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ExxonMobil Technology and Engineering

Bank Stability Assessment Manual

Water Crossing Program Technical User Guide Support Material

Revision 2.0 | December 2024

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Revision Record

Revision No.	Date Issued	Reviewed By	Description
0	2018	WCP SME	Development and release of bank stability procedure to accompany the Water Crossing Program.
1.0	03.2022	WCP SME G.R.	Incorporated learnings from BIPL including improvements to bank stability workflow, clarifications/improvements to Slope Stability Hazard Matrix; clarification on impacts of soil composition, field observations, etc. on overall geotechnical assessment; and updates to factor of safety guidance used for screening crossings and conducting more detailed bank stability assessment.
2.0	12.2024	Svetlana Shafrova, EMTech WCP SME T.N.	Incorporated learnings from over 2 years of application of the procedure, including adding discussions of interactive crossings, suspended pipelines, international work, and Cold Eyes Review; updates to factor of safety guidance based on 2024 factor of safety templates; and quality assurance/quality control of soil springs worksheet and general review and clarification of document text.

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Contents

© ExxonMobil Technology and Engineering | ExxonMobil Use Only

Tables

Figures

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Attachments

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Introduction

This *Bank Stability Assessment Manual* is a supplement to the ExxonMobil *Water Crossing Program (WCP) Manual* and *WCP Technical User Guide*. It describes how to assess bank stability as part of the WCP responsibilities performed by Water Crossing Engineers (WCEs); however, it does not qualify WCEs to perform the analyses. To perform bank stability assessments accurately, WCEs should have desktop screening experience as well as significant experience with the field inspection observations, making conservative assumptions, and decision making including professional engineering judgement.

The WCP Manual (and associated Global Manufacturing Training) provides an overview of the program from a Management and Operations/Sites perspective. This Bank Stability Assessment Manual solely focuses on describing procedures for assessing bank stability. It assumes WCEs are familiar with the WCP as described in the WCP Manual and WCP Technical User Guide.

All pipeline water crossings in the WCP inventory must be assessed for bank stability concerns. The purpose of this document is to explain the concept of slope stability and present procedures to follow while performing a water crossing bank stability assessment. Section 1 is an introduction to slope failures and how to assess indicators of instability. Sections 2 and 3 continue to provide background information on the bank stability evaluation process. The initial screening, site visit inspection, data collection, and stability ratings are discussed in Sections 4, 5, and 6. The bank stability ratings are associated with actions via the Slope Stability Hazard Matrix as detailed in Section 7. Actions may include a structural evaluation of the pipeline (Section 6.3), a risk assessment of the crossing (Section 9), and/or assigning interim monitoring and a High Water Action Plan (HWAP) (Section 10). When the assessment process concludes that a bank failure and/or pipe rupture are likely, pipeline shutdown or design of a pipeline and/or slope mitigation may be required to reduce risk.

Note that analyses associated with the WCP and assessing pipeline vulnerability to natural forces are complex. Bank stability assessment is not intended to be comprehensive engineering analyses on its own. This manual is intended as a reference document to provide WCEs with a baseline technical understanding and is not intended to be all-inclusive. It is intended to introduce technical concepts and tools but is not meant to supersede engineering best practices or hydrologic and hydraulic textbooks or technical documents. Professional engineering judgment in combination with insights from Operations/Sites are essential to successful estimation of present and possible future natural force threats to pipeline integrity at water crossings. This manual provides guidance based on the best-known information and practices at the time and should be reviewed and updated as needed to maintain accuracy.

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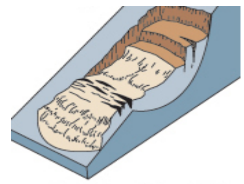
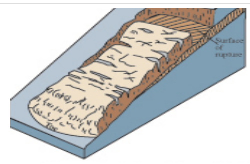
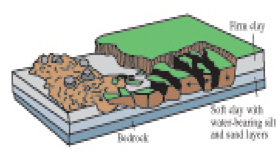
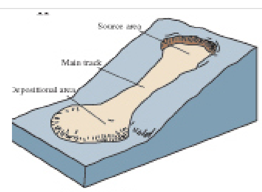
1 Slope Failure Mechanisms and Applicability of Procedure

Bank slope failure involves sliding and/or movement of a portion of an embankment relative to the adjacent mass. The slope movement has the potential to act upon buried a pipeline and/or increase the unsupported span length (USL) of a pipeline across the waterway. There are six types of slope failures according to Varnes (Reference 1) as shown in Table 1.

Table 1. Types of Slope Failures

Type	Description	Image
Slides	Rotational slides: masses slide outwards and downwards on one or more concave-upward failure surfaces that impart a backward tilt to the slipping mass, which sinks at the rear and heaves at the toe.	
	Translational slides: movements occur along planar failure surfaces that may run more-or less parallel to the slope.	
Falls	Masses are detached from steep slope/cliff along surfaces with little or no shear displacement (e.g., joints/fissures) and descend mostly through air by free fall, bouncing or rolling.	
Topples	Movements of rock, debris, or earth masses by forward rotation about a pivot point.	
Spreads	Involve the fracturing and lateral extension of coherent rock or soil masses due to plastic flow or liquefaction of subjacent material.	
Flows	Slow to rapid movements of saturated or dry materials which advance by flowing like a viscous fluid, usually following an initial sliding movement.	
Complex	A complex slide involves one of the main types of movement followed by two or more of the other main types of movement.	

This Bank Stability Assessment Procedure is only applicable to ***rotational*** slides, which typically occur along earthen channel banks of water crossings. Translational slides may have similar surface expressions on riverbanks and are likely to be also flagged for inspections. Flows can occur for sandy banks when inundated during flood

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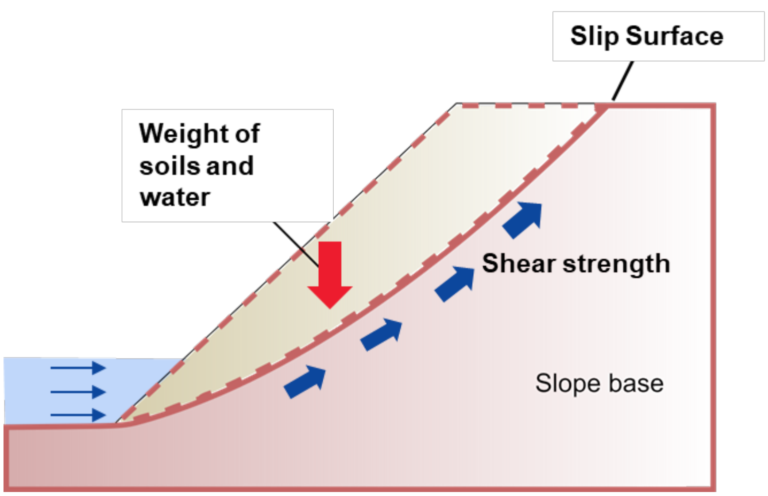
events. In engineering terms, a slide denotes the downward and outward displacement of slope material along a plane called slip surface. This shear failure is conventionally assumed to occur along a discrete, singular surface, although the shear movements may in fact occur across a zone of appreciable thickness – sometimes inches or feet across. Failure (or slip) surfaces are frequently approximated as circular in shape but can in fact be more complicated semi-circular surfaces of interconnected arcs and lines. The current methodology is based on the assumption that a failure occurs along an arc of a defined circular surface, as shown on Figure 1.

A slope failure occurs when the embankment is no longer in mechanical equilibrium because forces that are driving movement exceed the forces that serve to resist movement. The driving forces are the weight of the upslope soils and water (and potentially structures or live loads). Resisting forces are the shear strength of the soil along the slip surface and any weight and water forces on the lower portion of the slope. The slope stability factor of safety (FOS) is the ratio of resisting forces to the driving forces.

$$FOS = \frac{Sum\ of\ resisting\ forces\ (shear\ strength\ of\ soil)}{Sum\ of\ driving\ forces\ (weight\ of\ soil\ and\ water)}$$

FOS values less than 1 may be associated with imminent failure of the slope and requires action, the first being a review of the parameters and calculations by a Subject Matter Expert (SME) to validate the results. If a low FOS is confirmed, a series of actions are initiated as described later in this document. Therefore, the FOS is used as an indicator of the relative stability of the slope based on established loading conditions and failure criteria. Slope stability failures occur along the slip surface failure plane, as shown on Figure 1, that occurs when force equilibrium is exceeded by downward driving forces.

Figure 1. Driving and Resisting Forces of Slope Equilibrium



1.1 Loading Conditions and Failure Criteria

When required, evaluation of slope stability requires two steps: (1) establishing the “design soil conditions” and “water level conditions,” of which the slope may be subjected to during its life; and (2) performing analysis for these conditions. Typically slope stability analyses consider both short term and long-term loading conditions to evaluate a variety of soil stress/strength parameters that can lead to slope failure.

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The “short-term” condition typically refers to a condition where the soil is loaded at a rate faster than the pore-pressures can dissipate (drain) from the soil, resulting in the development of excess pore pressures. Fine-grained (e.g., clayey) soils behave as “undrained” during short-term loading condition while granular (e.g., sandy) soils behave as “drained” because the relatively higher permeability of larger grains allow for quick dissipation of excess pore pressures.

The “long-term” case refers to a condition where drainage equilibrium has been reached and there are no excess pore pressures due to external loads. Both fine-grained and granular soils behave as “drained” in the long-term condition. Shear strength of highly plastic clays can soften with time due to cycles of wetting and drying. For these soils, long-term stability analysis will need to be conducted using the fully softened effective friction angle.

For fine grained soils, stability analysis using drained and undrained shear strength will need to be conducted using the most critical water level condition in the crossing, which is usually the lowest water level in the channel (or normal water level if unknown) and conditions created after rapid drawdown (RDD). For granular soils, long-term conditions using drained soil parameters and lowest water level (or normal water level if unknown) as well as short-term conditions using drained soil parameters with seepage following bank inundation (i.e., RDD) usually represent the most critical stability conditions for the crossing. Mixed soils (e.g., silty and clayey sands) should be checked against conditions applicable for fine-grained and granular soils.

Loading conditions are directly related to surface water level in the stream channel and its associated groundwater level, or phreatic surface, within the slope adjacent to the water crossing. The phreatic surface represents zero pore pressure at the groundwater interface in the streambank and typically rises and falls with the fluctuations of surface water in the channel. The three loading conditions that can occur for a water crossing are shown in Table 2 along with acceptable FOS criteria that represent the minimum acceptable FOS for the water crossing to pass the screening stage.

The WCP utilizes conservative FOS criteria to determine which crossings are recommended for risk assessment, since slope movement can impact pipeline integrity. Water crossings that are engaged by a failure plane with FOS less than 1.5 for any load case and which exceeds pipeline structural limitations are recommended for risk assessment. Determination of FOS prior to risk assessment is described in subsequent sections of this procedure document. Moreover, crossings where slope failures have already been observed and have the potential to progressively expand and engages the pipe should also be risk assessed if preliminary analysis show that pipe capacity can be exceeded.

The WCP tools use conservative FOS criteria to avoid screening out crossings based on preliminary data which may be unconservative due to the high level of uncertainty. Therefore, additional data is collected to assess bank stability for a water crossing with an estimated FOS less than 1.5. One exception would be if signs of slope movement have already been observed and preliminary analysis indicates high risk to the pipeline integrity that would require quick mitigation before waiting for an updated stability analysis based on additional site investigation data.

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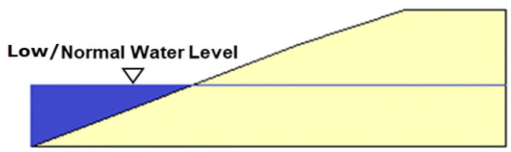
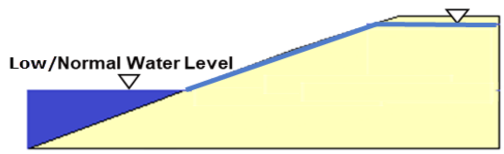
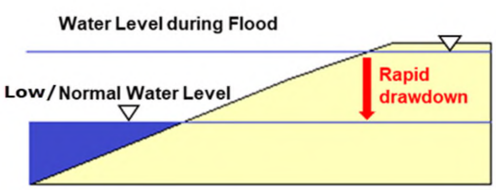
Table 2. Loading Conditions and FOS Criteria

Water Level Description	Image	Soil Strength Conditions to be Checked		Minimum FOS to Pass Screening Stage
		Coarse Grained Soil	Fine Grained Soil	
Normal Water Level (NWL) or Low Water Level (LWL) if known		Drained (i.e., effective stress parameters)	Drained, Undrained, and Fully Softened	≥ 1.5
Seepage After Bank Inundation (Excess Pore Pressure Conditions)		Drained (i.e., effective stress parameters)	NA	≥ 1.5
Rapid Drawdown (RDD) of Water Levels		R&S Strength Envelops for “Dirty” Granular Soils	R&S Strength Envelopes Incl. Fully-Softened Conditions	≥ 1.5

RDD conditions cause a majority of slope stability failures on channel banks due to the increase of the soil weight from water saturation and the reduction of the soil’s shear strength for most fine grained (clayey) materials. For bank stability assessments, granular materials are assumed to have fully saturated slopes and an empty channel or lowest surface water level (if known) to represent a conservative scenario that resembles RDD. For that reason, the tools developed for this bank stability assessment procedure focus on evaluating the RDD loading condition.

FOS estimations used to evaluate bank stability are based on the RDD load case with saturated slopes as described in Section 7.1. The LWL condition (or NWL if the LWL is unknown) should be checked for slope stability and/or slope mitigation during detailed analysis for crossings that do not pass the screening stage. Evaluating the high water level (HWL) does not add value to the assessment due to the stabilizing effect of the weight of water on the slope. HWL conditions are addressed by the WCP scour and erosion tools because the velocity and height of the river also impacts the bank slope.

1.2 Pore Pressure Response During Rapid Drawdown

The modeling of slope stability during RDD requires estimating the pore water pressure within the slope prior to drawdown (high water) and after drawdown. Typically, the pore pressures prior to drawdown are estimated assuming that the slope will be fully saturated up to the upper water pool level but the pore pressures in the slope following drawdown are more difficult to estimate because they depend on the duration of the flood and the soil drainage characteristics. In general, the more saturated the slope is assumed to be following drawdown, the more

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conservative the assessment of stability will be since higher saturation leads to higher pore pressures and lower effective stresses.

Clayey slopes have low permeability and would not be expected to become fully saturated during a flood event; consequently, they would not be expected to drain significantly following drawdown. Conversely, sandy slopes have relatively high permeability and therefore can become fully saturated during a flood but should drain following drawdown. For sandy slopes, it is possible that seepage can appear along the slope face during drawdown. The stability screening tools described in this document use the conservative assumption of saturated bank slopes for both clayey and sandy soils due to the uncertainty of soil parameters. When performing the more detailed bank stability assessment and risk assessment, assume that banks will become saturated once water level rises.

1.3 Combinational / Interactive Crossings

When assessing waterway crossing threats, the potential for interactive hydrotechnical (scour, erosion, avulsion) and geotechnical (bank instability) hazards must be considered because they are often related. Hydrotechnical forces causing erosion are not solely responsible for causing bank instability. However, steepening of the slope and erosion of the bank's toe can affect local and global stability. The toe of the bank provides resistance against the gravitational forces acting on a slope, and loss of the mass of the toe can cause bank instability by removing the stabilizing force against sliding. In turn, the resultant bank instability can induce significant stress on a pipe and potentially loss of containment. Chanel and overland flow may steepen the bank slopes beyond the soil's angle of repose and create potential instability where failure may be initiated by low water or RDD conditions. Additionally, shallow (local) failures, often called sloughing, can, over time, decrease cover over the pipe within the bank, leading to exposure or suspension. These shallow failures can also induce internal strain within the slope, which can cause structural strain to the pipeline without exposure/suspension.

The WCE should focus on integrity threats due to natural forces regarding hydrotechnical considerations (i.e., flooding related) and geotechnical considerations (i.e., landslides); however, it is also critical to assess where a pipeline may be susceptible to interactive natural force threats, also called "combinational" crossings. The WCE must understand the how the erosion processes interact with bank instability and take them into account when determining water level or rainfall thresholds for a HWAP or trigger monitoring.

When performing screening, inspections, and scorecards, any suspected hydrotechnical threat should be communicated to the hydrotechnical SME to ensure it has been captured in their evaluation and modeling. The hydrotechnical SME may provide flood frequency and scour potential information that will be useful in the stability evaluation of the banks.

1.4 Excess Pore Pressure Conditions

For sandy slopes, excess pore pressures have been known to initiate flow liquefaction under special conditions. Flow liquefaction occurs when a saturated matrix of fine-grained sandy material suddenly behaves undrained and/or large excess pore pressures develop that may initiate large deformations. Normally, the strength behavior of freely draining sandy material is characterized as drained, and pore pressures in excess of steady state do not develop. However, under special conditions such as from an earthquake or rapid loading, an undrained response may occur. While seepage conditions from RDD may not create undrained response in sand, it does increase the pore water pressure in the sand which decreases its drained shear strength. The increase of pore pressure and the corresponding reduction of effective stress initiates slope instability where sand may flow like a viscous fluid. It

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should also be noted that flow liquefaction has also been observed in slopes with dense sand. The failure mechanism is more complex in this case and starts with the erosion of the slope toe from water flow causing an increase in the slope angle in this section of the slope. This causes the dense sand layer close to the toe to dilate, creating negative pore water pressure which attracts more water into the slope and results in a decrease in the sand's shear strength and failure of this section of the slope. The same process repeats itself (very quickly) on the newly created slope face with the ultimate result of the slope failing progressively in a flow-like failure.

Three conditions are necessary for a flow slide to occur: (1) presence of sand or non-plastic or plastic sandy and silty soils; (2) slope geometry must be unfavorable (i.e., steep); and (3) an initiation mechanism must be present. In this case the initiation mechanism is increased pore pressure from seepage or a seismic event. Induced pore pressures from sudden changes in loading may not dissipate quickly enough in sand (especially dirty sand) to prevent slope movement.

The resulting FOS for RDD analyses of sand banks were not considered sufficiently conservative for screening purposes. The more conservative analyses that employ pore pressure ratios with saturated slopes are used for screening embankments that become inundated during flooding because they will result in highlighting sandy slopes that may have marginal stability or the potential to become marginally stable. Therefore, evaluation of sandy slopes includes the assumption that excess pore pressures exist.

2 Bank Stability Workflow

Bank stability screening is performed as a series of screenings and assessments that are repeatedly reviewed until the potential threat of slope failure is quantified. By combining aspects of the Bank Stability Screening Tool and the Slope Stability Hazard Matrix, the pipeline water crossing is evaluated for potential threats and results are used to determine appropriate next steps and actions. The Bank Stability Assessment Workflow is shown on Figure 2. The workflow encompasses a series of activities, tools, and resources. The process starts with an initial desktop screening that undergoes a series of iterations and SME reviews to determine whether a bank slope proceeds to the next step of review, the Bank Stability Scorecard evaluation. The Bank Stability Scorecard quantifies failure probability as color codes from a similar list of questions. Each iteration includes additional site-specific data obtained from surveys, plans, visual observations, or information from Operations. Quality assurance and quality control (QAQC) is performed at each step of the workflow. Internal review of the screening and Bank Stability Scorecard forms is required for WCEs with less than 6 months experience. The Slope Stability Hazard Matrix ultimately helps determine the actions taken based on pipeline vulnerability, as discussed in Section 7.

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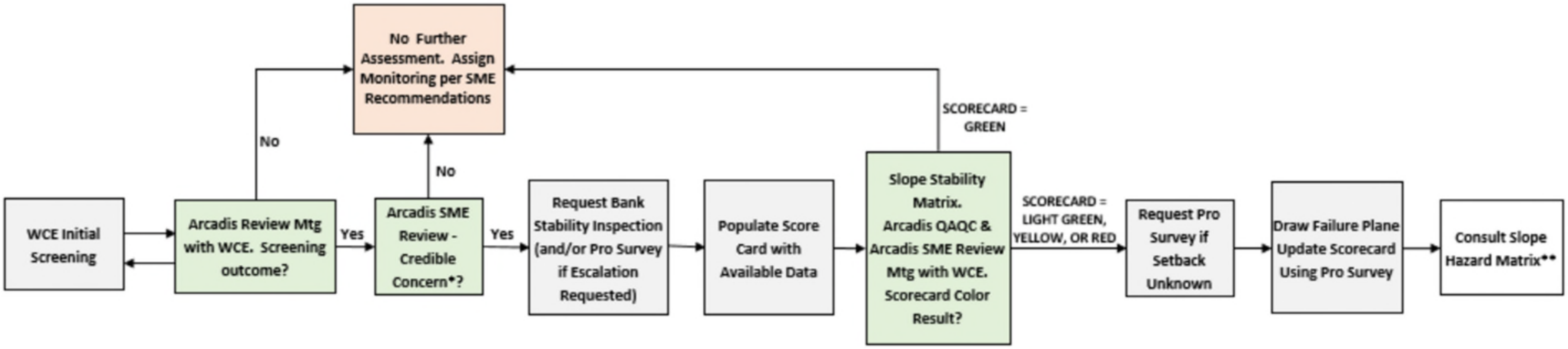
Figure 2. Bank Stability Assessment Workflow



Gray = WCE Actions
Green = Arcadis / SME Involvement
Orange = Document and Stop

*If Third Party SME reduces Bank Stability Screening score from "Yes Credible Concern" to "No Credible Concern" based on interpretation of crack photos, WCE should review crack photos with WCP Coordinator prior to filtering out the crossing for Bank Stability Concerns.

**Based on slope hazard matrix, additional investigation and actions may be needed such as Slope W modeling, Pipe Strain Calculations, Risk Assessment, HWAP, Scheduled Monitoring and/or Mitigation.

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3 Basis of Assessment

The basis for the bank stability assessment process is that certain observable items within a channel and its floodplain allow for preliminary identification of geotechnical movement or potential failure of slopes that may cause additional stress upon pipelines. The assessment can be broken into two parts: (1) the stability of the bank slope; and (2) the vulnerability of the pipeline. The stability of the bank is related to the likelihood that the bank will experience a failure. Taller banks, steeper slopes, and banks suffering erosion are generally more prone to fail. Using a series of observations, it can be determined whether the right and left banks at a crossing are stable, if further details are required, or if SME input is needed to determine the probable bank stability. Pipeline vulnerability is based on whether the pipeline is sufficiently buried (i.e., depth of cover) with adequate set back distance from a potential critical slope failure surface (with a safety factor less than 1.5) to make it less likely to experience any forces during the bank failure. If the pipeline is not sufficiently buried, then the assessment should focus on estimating the additional forces/strain on the pipe from a potential movement of a slope failure surface with a safety factor less than 1.5 that engages the pipe.

3.1 Forces on the Pipeline

The principal limit states or failure modes for continuous pipelines are rupture due to: (1) axial tension and/or bending; and (2) local buckling due to axial compression and/or bending. Axial forces and bending moments in a buried pipe are caused by forces at the soil-pipe interface. Movement of the surrounding soil with respect to the buried pipeline may force the pipeline to move with the soil or result in differential movement between the pipe and the soil.

Ground deformation can be comprised of longitudinal components (soil movement parallel to the axis of the pipe) and transverse components (soil movement perpendicular to the pipe axis). A pipeline that is relatively near or crosses a failing slope can be subjected to both longitudinal and transverse ground deformations depending on its orientation relative to the failure zone. Under longitudinal ground deformation, a continuous pipeline may fail at welded joints, buckle locally in a compressive zone, and/or rupture in tensile zone. Figure 3 illustrates longitudinal slope loading a pipeline while Figure 4 shows transverse slope loading of a pipeline.

Figure 3. Longitudinal Slope Loading

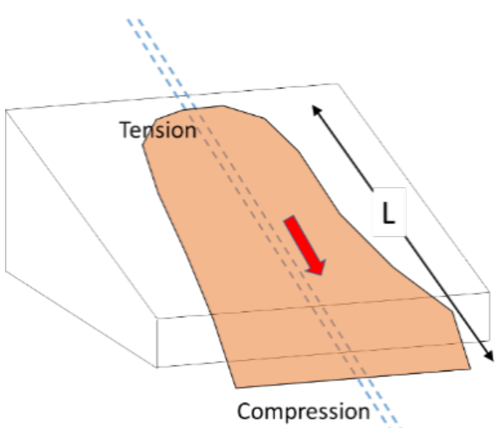
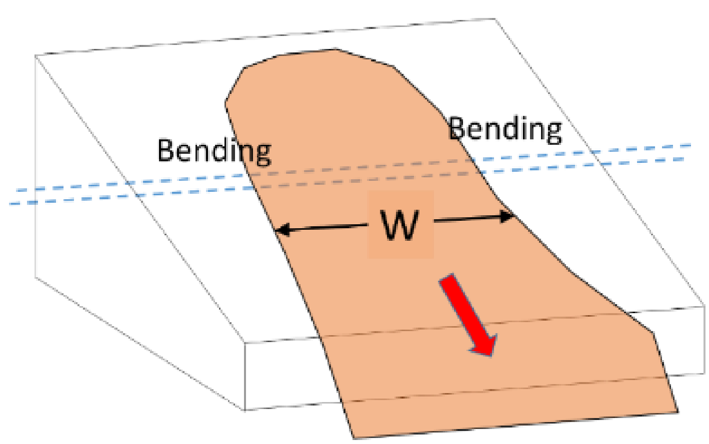


Figure 4. Transverse Slope Bending



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When subjected to a transverse ground deformation, a continuous pipe will stretch and bend to accommodate the imposed displacement. The failure mode depends on the relative amount of axial tension and flexural strain. If axial tension is small, the pipe wall may buckle in compression due to excessive bending. If axial tension is large, the pipe may rupture in tension due to the combined effect of axial tension and flexure.

To simulate geotechnical forces, engineers can model the forces using ***soil springs*** or p-y (pressure-deflection) curves. Soil springs are oriented such that both longitudinal and transverse components of soil movement are represented by separate, independent spring forces. **Attachment A Soil Spring / Permanent Ground Deformation Calculations** includes the WCE procedure to calculate stress and strain on the pipeline. Please note that this procedure provides very preliminary assessment and only considers soil movement in one direction (either axial or lateral) and assumes that the engaged pipe length is the governing factor. A more detailed analysis considering soil type, pipe properties and profile, and slope movement distribution in at least two directions (e.g., axial and vertical for crossings perpendicular to the slope) should be employed when pipe is expected to be engaged by slope movement that has already been observed or predicted by analysis as discussed in the previous section.

If the forces expected to act upon the pipe are greater than those allowable by code, the crossing should be risk assessed. If the forces expected to act upon the pipe are not greater than those allowable by code, the WCE and SME should confer on the level of conservatism. Given that multiple failure surfaces with different safety factors may engage different pipe lengths, it is necessary that this assessment is conducted for multiple failure surfaces that represent the most critical combination of safety factor (which governs degree of slope movement) and engaged pipe length. This is usually achieved by looking at the most critical failure surface that engages the pipe and the failure surface with a safety factor equal to 1.5 if the former has an safety factor less than 1.5. Consult with the SME before deciding whether a risk assessment is warranted. Additional details are provided in Section 8.

Due to the large amount of force required to rupture a pipe, longitudinal slope loading soil springs is only needed for slopes 50 feet or taller. Transverse loading has a greater impact width.

4 Bank Stability Screening

An initial desktop screening utilizing the Bank Stability Screening Tool may be completed by the EMPCo WCE or the WCP Implementation Lead at the Bangalore Technology Center (BTC). **Supplemental Screening Guidance** is provided in **Attachment B-1** and an example screening checklist is provided in **Attachment B-2**. The screening is performed before collection of any field data. The desktop screening is performed with data readily available to the reviewer, which may include photos from previous site visits, aerial images, Google Earth/Street View, or prior knowledge from pipeline operations. All pertinent data used for the screening should be documented in the screening workbook, especially the date of aerial imagery used for the evaluation. Based on this initial assessment, the reviewer may determine that the potential threat to bank stability is unlikely at the subject crossing. This may be based on items such as height and/or slope of bank, vegetation density, or other available data pertinent to the evaluation. If a crossing is unable to be evaluated by desktop screening or removed from consideration (e.g., if a crossing is not visible in Google Earth due to tree coverage or poor resolution), then the crossing should be listed for a bank stability inspection to begin the process of filling data gaps unless construction drawings indicate a low likelihood of bank instability.

It is recommended to identify other parallel or perpendicular crossings that have any of the following characteristics for which information for those crossings can be leveraged in the bank stability screening of the water crossing being screened:

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- Crossings with reported or documented bank stability concerns along the same waterbody or the general geographic location/setting;
- Crossings with credible concern that a change to the bank geometry could lead to the pipeline exceeding physical limitations (such as bending in air/water, debris forces, vortex-induced vibration, etc.); or
- Crossings with existing countermeasures to protect against erosion, scour, and bank loss such as bulkheads, palisades, rip rap, matting, etc. (The latter excludes mitigation efforts designed by licensed engineers.)

Public imagery is available through Google Earth, Google Street View, Microsoft Bing's Birds Eye view, which can be used to estimate bank angle, bank height, conditions of vegetation, erosion features (e.g., widening of the channel, undercutting), presence of drainage outlets such as culverts, bank modifications by others, and signs of bank instability (e.g., scarps, cracks, slumps, leaning trees). Dates of the imagery used should always be documented. Drainage structures such as culverts should always be noted due to their impact to flows and erosion. Google Street View of nearby bridges crossing the same water feature may provide a good view of the banks. Aerial image resolution may drop off outside of urban areas and may not be as useful. Geographic Information System (GIS) databases exist with high level topography that can be used to develop conservative bank slope conditions. In some cases, GIS databases with low altitude, high resolution aerial imagery and LiDAR is available along the pipeline corridor that allows evaluation of slopes above and below the pipeline.

It should be noted that the frequency of Google Earth images is primarily based on the location's population density, with highly populated areas receiving more frequent updates (yearly) compared to sparsely populated regions which may only see updates every few years. Thus, some crossings will have abundant images to observe the changes over time and will likely have a clear image without clouds. Screening in remote areas becomes more difficult with a limited number of images.

It is important not to use imagery taken before the construction of the pipelines. Typically, the construction process can be identified by absence of topsoil and crane lagging along the corridor. The construction date is needed to prevent the evaluation of previous slope and bank conditions that were likely improved during construction. Sometimes the latest aerial image is of the construction phase and current conditions of the pipeline crossing cannot be assessed. It is also important to note the season of the imagery date (i.e., winter, spring, summer, fall). The best views are obtained in late fall season when the leaves are off the trees allowing an unobstructed view of the corridor. Vegetation often turns brown in the fall and should not be confused with erosion, since the root system remains intact all year.

The next step in the bank stability workflow is to populate the Bank Stability Scorecard – but only if the following criteria are met:

- Crossing does not appear to have any concerns (i.e., Bank Stability Screening Score is "No").
- The bank is less than 6 feet (2 meters) tall and has a horizontal to vertical (H:V) slope greater than 2:1.
- The bank slope is less than 15 degrees (>3.5H:1V) unless signs of erosion, channel migration, pipe exposure, or bank sloughing and instability have already been observed.
- Both banks are lined with concrete that is in good condition.
- Horizontal directional drilling (HDD) pipeline with at least 20 feet depth of cover and setback known to be greater than ¼ of the channel width.

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If any concerns are identified, or if insufficient data is available to identify potential bank stability concerns, a site visit and/or bank stability inspection is recommended for the crossing. Figure 5 provides examples of water crossings to be evaluated.

All screening tool spreadsheets should be undergo a QAQC process for an in-depth review prior to making final decisions as to which crossings require additional site data or are filtered out for bank stability concerns. Screenings performed by BTC should be reviewed by a senior employee before being sent to Arcadis. Arcadis will perform an initial review and then send all crossings that filter as “Yes” for potential bank stability concerns to a Third Party geotechnical SME for further study. The geotechnical SME comments and recommendations should be communicated to the WCP Technology Leads in a workbook that summarizes the findings. The summary workbook should be shared with the screeners as a learning tool to allow improvement of their performance. The WCE should save all QAQC feedback to the individual crossing folder. If a Third Party SME concludes that a crossing that was originally marked as having potential bank stability concerns does not have concerns based on their interpretation of data, then the WCE should review the comments with the WCP Technology Lead before filtering out the crossing for bank stability concerns.

Figure 5. Examples of Water Crossings Reviewed for Bank Stability

Left: Crossing that would require a bank stability assessment due to scarps.

Right: Crossing where slope stability is not a concern due to vegetation and flatter slopes (roadway ditch).

4.1 Rest of World Stability Screening

Availability of publicly available imagery in countries other than the United States may be limited due low population density and/or privacy laws. Specifically, Google Street View is sometimes not allowed to protect the privacy of residents (i.e., Germany). In these cases, there may not be a land view or high-resolution image of the terrain and water crossings.

5 Bank Stability Inspection

When the initial desktop screening results indicate a site visit is needed, the Bank Stability Inspection Checklist is completed by surveyors or Operations personnel who have been trained to fully document the site conditions and available information. The Bank Stability Inspection Checklist asks a series of questions to help identify potential bank threats that can be visually observed in the field or may be known by Operations staff who are familiar with the crossing. The Bank Stability Inspection request should be issued with other survey requests on Form 4.1 when possible. Inspections should be made by personnel familiar with the Bank Stability Inspection Checklist and who have attended the WCP training whenever possible and inspections should be scheduled to occur when the banks are accessible and safe. All Bank Stability Inspection Checklist questions should be addressed by the personnel conducting the site inspection.

The basis of the Bank Stability Inspection Checklist and an example Survey123 Field Application form, provided in **Attachments B-3 and B-4**, respectively, are used to document the presence of conditions typically associated with slope instability. It includes the following sections related to the water crossing:

a. General
   The general section of the Bank Stability Inspection Checklist is meant to determine regional affects that may produce additional stability concerns. The questions include recent drought or flood events that may weaken soil, debris build up that may impact the pipeline, adjacent pipelines that may catch debris or cause turbulence within the stream, or nearby bank armoring or modification that may indicate erosion/stability problems exist. Some of the questions may not be easily answered by a site visit, but knowledge of these items by local Operations staff may be more likely and accurate than the WCP.
b. Floodplain and Channel Migration
   The Floodplain and Channel Migration section describes the long-term changes that may be occurring at the top of banks or in the floodplain. This includes washouts draining over the high bank into the channel, trees falling into or soon to be falling into the channel, visible erosion, or soft areas with ponded water that may put extra weight on the soil above the banks.
c. Bank Stability Questions
   The Bank Stability questions consist of descriptions of the banks themselves. This includes bank soil geometry in the form of slope and height and material characteristics such as soil type and soil strength. A table of slope conversions to multiple formats is provided in **Attachment B-5**. Site details should be collected during the field inspection to limit the number of site visits required to assess the bank stability. The Bank Stability Inspection Checklist also includes typical signs of bank slope distress, such as undercutting, seepage, cracking, animal burrows, scarps, and depressions. WCP training has been developed to explain and help identify these threats in greater detail, including how to measure bank geometry, determine soil types, and identify signs of distress. *Completing the Bank Stability questions during inspection and assessment is crucial to qualifying slope stability threats using the Bank Stability Scorecard criteria.*

Most questions can be answered based on field observations, while others require more detailed evaluation using the resources available such as hydrologic studies, surveys, construction drawings, and other available data. In all cases, the WCE should verify and validate the inputs of the Bank Stability Inspection Checklist and obtain missing information if/when available.

5.1 Rest of World Inspections

WCEs assess water crossings in countries outside of the United States. Staff in some Rest of World countries may not be familiar with the evaluation procedures described in this manual and may require coaching to ensure a quality evaluation (the exception being Canada due to frequent cooperation with the WCP). The first step is for the WCE to reach out to the Pipeline Integrity Advisor in Asia or Europe to learn who the appropriate contact is in the area of the crossing(s). Virtual meetings with the area staff are encouraged to explain the how and why of the crossing

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evaluation. Communication must be clear, concise, and well documented due to differences in pipeline terminology. Alignment meetings with multiple international teams at once (except Canada) should be used to explain the process, background information, and any updated procedures. A long-term goal for the WCP is to have a specific person trained to perform field inspections in each area.

6 Bank Stability Scorecard

Desktop screenings that result in a SME confirmed “Yes” for bank stability should proceed to the Bank Stability Scorecard. Inputs from the Bank Stability section of the Bank Stability Inspection Checklist are transferred to the Scoring Sheet after parameters have been verified and validated by the WCE. The WCE should use conservative assumptions for the 12 Bank Stability Scorecard questions (discussed in Section 6.1) relative to the availability of detailed site-specific data on the bank slopes and soil materials. When field observations are not available, the WCE can attempt to complete the Scoring Sheet using available site imagery and information, which may include survey files with terrain data, overbank drainage patterns, terracing, and/or erosion over time (in surveys including multiple years), along with pipeline information regarding the installation depth and setback distances. An example Bank Stability Scorecard is included in **Attachment B-6**.

6.1 Bank Stability Scorecard Criteria

6.1.1 Question 1 – Slope and Height

Bank height and slope ratio should be based on the Bank Stability Inspection or a professional survey. The bank height should be measured from the toe of bank at the streambed to top of bank and reported in feet. Horizontal distance should also be measured from toe of bank to top of bank and must have an angle of attack correction applied if the pipeline is not located perpendicular to the direction of channel flow. Surveys follow the pipeline stationing across the channel and may not be perpendicular to the banks. When the plan view shows the angle of attack at a skew to the channel, the profile may require interpretation to obtain a corrected slope ratio as explained in **Attachment C Angle of Attack Correction on Cross Section of Pipeline Calculation**.

Bank slopes are often steeper at the upper part and flatter at the bottom, unless significant toe erosion exists. The origin of all utilized data should also be recorded. A professional survey provides the most accurate measurements and should be used by the WCE to answer this question when available. The slope ratio should be reported as horizontal to vertical (H:V) distance. The Bank Stability Scorecard should be populated for both the left and right bank based on survey and visual inspections. For banks with large heights and complex profiles, the local slope with the steepest profile within the bank should also be assessed.

6.1.2 Question 2 – Soil Type (or Classification)

The Unified Soil Classification System should be used to describe the soil type along the bank slope based on the best available data that may include the following: field observations, United States Department of Agriculture soil survey series, and/or site-specific subsurface investigation laboratory data and/or boring logs. Note that surficial soil samples such as topsoil or alluvium may not be representative of the soil type and strength of material within the bank slope where the failure plane occurs. If practical, the WCE should attempt to observe the soil characteristics underlying the organic topsoil or alluvial material. The WCE should observe the soils near the top of the bank as well as on the bank slope if safe to do so. Typically, there will be some variation in the soil composition

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along the bank slope and the WCE should make a conservative estimate of the predominant soil type. Loose sands or soft fat clays produce lower slope stabilities and should be selected even if they represent a small portion of the bank. In addition, stiff fat clay can soften with time and assessment using soft fat clay should also be conducted for these crossings.

6.1.3 Question 3 – Bank Soil Strength (or Consistency)

Relative soil strength is estimated based on soil consistency. Clayey soil has strength related to cohesion (i.e., soft to stiff) while granular material is evaluated by density and cementation (i.e., loose to dense). Cohesive, clayey soil often moves downward uniformly and may apply larger forces to buried structures in its path while a sand bank with no cohesion would more than likely erode during a high water event.

The soil type (classification) and relative soil strength (consistency) can be estimated by the WCE in the field by using the ribbon test, thread test, and thumb indentation test as shown in the assessment training PowerPoint slides. In addition to field observations, other data that may be helpful include soil data from the United States Geological Survey (USGS) Soil Web, the Texas Water Development Board's Groundwater Data Viewer, and historical soil investigations (if available). When field observations are unavailable the WCE should use conservative assumptions based on regional soils data or other available information obtained during the desktop screening. Soft fat clay and loose saturated sand are the soil compositions that are most likely to lead to slope instability.

6.1.4 Question for WCE – High Water Events

The potential for the bank slope to get inundated due to flood events (i.e., high water event) is based on available data and historical operations. High water events are classified as events where the water level in the stream rises above mid-height of the bank, and up to or above the top of bank. In the field, previous high-water levels are typically marked by debris deposited along the upper portion of the slope.

Bank stability conditions may deteriorate from saturation or changes in geometry during an intense rainfall/high water event especially if the banks are expected to be inundated. High water events are particularly detrimental to bank stability if the water level rises and then recedes quickly (e.g., rising and then returning to normal water level within 24 to 72 hours), which creates RDD conditions. The WCE should explore data from USGS stream gages or other publicly available information, review Rapid Scour Screening Tool (RSST) outputs, and discuss the potential for high water events with local Operations. This information may be used to develop a HWAP if dictated by the final score.

6.1.5 Question 4 – Vegetation Cover

The condition of bank vegetation is based on site observations along with Google imagery and previous site inspection photos. Historical aerial imagery may show changes in the vegetative cover of the slope over time. Typically, well vegetated slopes tend to be less prone to instability. The WCE should also document changes in vegetation of the slope – if the slope has experienced a loss of vegetation, then it is more prone to instability due to the loss of the stabilizing effect of a root system. Figure 6 provides examples of varying magnitudes of vegetation on a slope.

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Figure 6. Examples of Slope Vegetation

(a) Sparse, little to no vegetation

(b) Fully vegetated slope with grass and shrubs, or mature tress

(c) Light vegetation – mostly grass, weeds, few trees and shrubs

6.1.6 Question 5 – Seepage From Slope Face

Seepage is based on site observations and is usually expressed as wet areas or water flowing on the bank slopes. Seepage or springs daylighting along the slope may be indicated by different vegetation such as cattails or patches of greener or taller vegetation. Estimated flow quantity and location should be recorded. Documentation should include whether the discharge is muddy or clear (turbidity), as muddy discharge may indicate that internal soil erosion is occurring. Internal erosion is the transport of soil particles through the slope by water that may eventually lead to the formation of voids within the bank that may collapse. Figure 7 shows water collecting near the toe of a slope, which is indicative of seepage.

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Figure 7. Examples of Seepage Ponding at Toe

6.1.7 Question 6 – Land Drainage

Surface drainage of runoff is based on site visits in conjunction with aerial imagery (if available). Surface water runoff that travels over a bank slope can be detrimental to the stability of the slope; therefore, it is important for the WCE to determine whether there is runoff/drainage going over the bank and down the slope. If the quantity/intensity of the runoff is sufficiently high it will create erosion gullies on the slope face, and if observed should be documented. Over time, erosion gullies can increase in depth/size if the bank is not appropriately protected from overland drainage. Continuation of flow down the slope will increase the size of the gullies and contribute to bank instability. Erosion may also reduce the depth of cover to the point of pipeline exposure. A photo of overland flow is shown on Figure 8.

Figure 8. Example of Overland Flow Causing Erosion on Bank Slope

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6.1.8 Question 7 – Previous Slides or Failures

Site observations are also used to assess historical slides and slope failures. Bulging near the toe of the slope or vertical scarps near the slope crest (as shown on Figure 12d in Section 6.1.2) are typically indicative of previous slides that may still be active. If the WCE observes bulging near the toe or vertical scarps on the slope, the location and size of these features should be recorded. A major concern is that the material that moved to the base of the slope will erode in the stream, unload the toe, and accelerate slope movement. The threat of these features is determined later in the process and based on the failure plane's proximity to the pipeline.

6.1.9 Question 8 – Undercutting/Erosion

Site observations should be used to identify the potential mechanisms of erosion and detect the presence of existing undercutting/erosion on and near the bank slope. While the FOS tool does not account for erosion processes, it is important for the WCE to be able to identify the magnitude and type of erosion since erosion processes can significantly reduce the stability of the bank. This is of particular importance for sandy slopes because sandy soils along a slope face are prone to progressive erosion due to successive high water events that can eventually lead to bank failure. Figures 9 and 10 show typical erosion processes that should be documented by the WCE if encountered during field observations. The WCE should also utilize historical Google Earth imagery to determine changes in channel geometry over time that can be indicative of ongoing bank erosion.

Figure 9. Bank Undercutting Due to Scour or Erosion

The undercutting creates an overhang, which may collapse and undermine bank stability.

Figure 10. Example of Bank Undercutting Creating Overhang Due to Scour or Erosion

6.1.10 Question 9 – Ground Cracking

Site observations should be used to detect the presence of ground cracking on and near the bank. Examples of cracks are shown on Figure 11. Ground cracks on the slope or crest may indicate that some slope/bank movement

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has occurred and that there is a potential for continued movement that could lead to bank failure. In addition to recording the presence of cracks, the WCE should also document whether the cracks are parallel or perpendicular to the crest; the orientation of the cracks indicates the potential direction of slope movement since slope movement typically occurs in a direction normal to the orientation of the cracks. The WCE should document the following information if cracks are present. Cracks should also be mapped during professional surveys.

- Note location/lateral extent, and orientation, of cracks with respect to the pipeline.
- Record width and depth of cracks, if practical.

Figure 11. Example of Ground Cracks That May Indicate Movement of Slope

6.1.11 Question 10 – Surface Depressions

Site observations should be used to detect the presence of depressions and sinks, examples of which are shown on Figures 12a and 12c (see Section 6.1.2). Depressions or “sinks” can appear near slopes for different reasons but typically occur due to internal soil erosion (e.g., loss of soil particles) that creates a void below the ground surface, which manifests as a surface depression. Internal soil erosion can occur due to groundwater flow caused by seepage through the bank slope or due to the presence of below ground utilities (e.g., drainage pipes, water, or sewer lines) that are either leaking or have poorly compacted soil surrounding the utility line that settles over time (i.e., subsidence) creating a depression reflected on the ground surface. Areas of karst may have large voids such as caves within the limestone bedrock that sometimes collapse and cause a large depression at the ground surface.

6.1.12 Question 11 – Animal Burrows

Site observations should be used to detect the presence of animal burrows, which may be above or below the normal water level. An example burrow is shown on Figure 12b. Burrows may change the slope geometry, weaken banks, and create pathways for seepage and internal erosion within the slope. Burrowing animals such as groundhogs, muskrats, and armadillos are common near streams.

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Figure 12. Examples of Sinkholes/Depressions, Animal Burrow, and Scarps

(a) Depression or "sink"

(b) Animal burrow

(c) Depression or "sink" with ponded water, typically indicates presence of clayey, poorly drained soils

(d) Vertical scarp near crest indicates active slide

6.2 Slope Vulnerability (Scorecard Scores/Factors of Safety)

Once the color codes are derived from the Bank Stability Scorecard as shown on Figure 13, the WCE proceeds to the next steps of the evaluation process. The first step is a review by a SME to confirm that the responses to the questions reflect the observations. Scores may be overridden based on SME interpretation and guidance. In this case, the WCE should document the recommended score with an explanation of why a different color code was recorded. If the Third Party SME concludes that a crossing that was originally marked as having potential bank stability issues does not have concerns based on their interpretation of photos, then the WCE should review the photos with the WCP Coordinator before filtering out the crossing for bank stability concerns.

Bank loss due to slope failure can have variable effects on the pipeline. It can expose a previously buried pipe to natural forces for the first time, and/or increase the USL or impart forces to the pipe causing its rupture. Bank movement or loss due to instability is considered an event of concern since the failure mode can be reached during and/or following a single return period storm event. When bank loss occurs in small steps over time, this can be considered an ongoing bank erosion threat because material along the lower slope and toe may wash away. An SME assessment will identify whether the threat is a bank erosion rather than larger bank stability concern such as progressive failure. Erosion may be addressed with a scour (i.e., RSST) evaluation, flow-based monitoring, and slope protection mitigation measures. Crossings that have yellow scores based on erosion alone should still be classified as “Conditionally Stable” banks in the water crossing database.

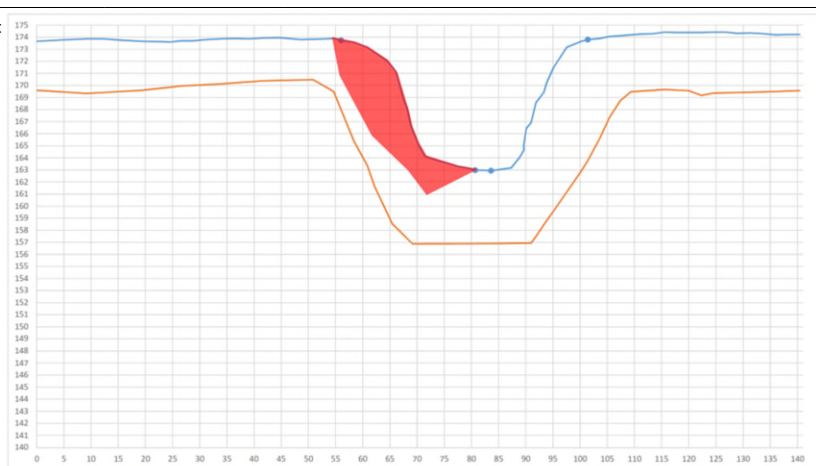
Figure 13. Bank Stability Inspection Checklist Scoring Sheet Example

ExxonMobil Global Pipeline Integrity
Water Crossing Program Bank Stability Site Inspection Question/Checklist

Revision 5

Bank Stability Questions:		**Yes**	**No**	**Rationale**
1	Slope Ratio and Height (first box horizontal to vertical ratio, second box height in feet)	2.3	10.8	GREEN
2	Bank slope soil type: a) Fat clay; b) lean clay; c) silt, d) sand	b		
3	Bank slope soil strength: a) Stiff, strong or very dense; b) soft, weak or loose	a		
	FOR WCE - Can the bank ever get fully inundated	x		
4	Vegetation cover on slope face: a) Well vegetated with trees; b) light vegetation (mostly grass); or c) no vegetation	b		GREEN
5	Seepage from slope face: Is there evidence of groundwater seepage exiting from the slope of the banks above the typical low water line? (This is sometimes indicated by patches of different vegetation)		x	GREEN
6	Land drainage: a) Flat; b) minor drainage over slope; or c) drainage over slope with erosion gullies	b		GREEN
7	Erosion: Is active erosion visible at the crossing (or upstream and downstream)?	x		YELLOW
8	Undercutting: Are trees on the bank with exposed and overhanging roots?	x		RED
9	Are any soil cracks on the slopes or above the banks? Note if parallel or perpendicular to stream and note the amount of displacement (width).		x	GREEN
10	Are depressions or larger sinkholes within or near ROW?		x	GREEN
11	Are animal burrows present on the slope face?		x	GREEN
	SCORE			**RED**

Survey Mark Up Screenshot



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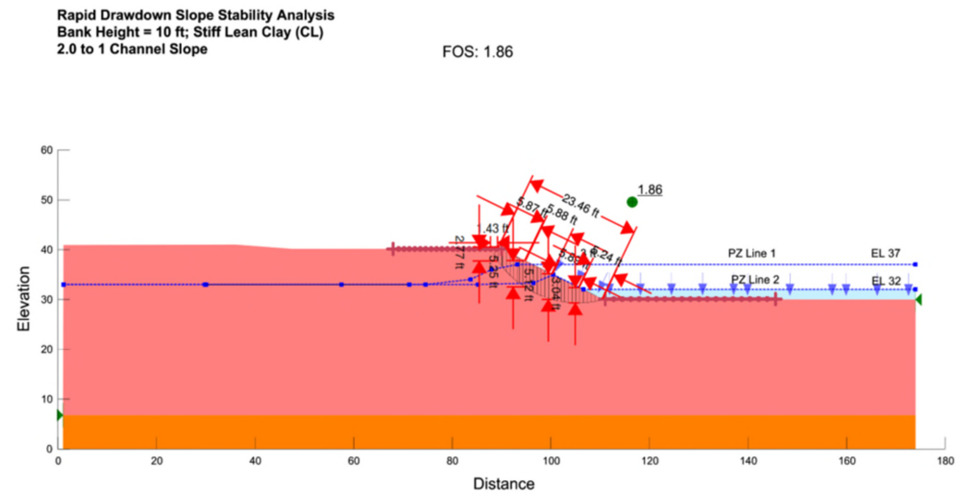
FOS Tool Screenshot



FOS are integrated into the Bank Stability Scorecard based on the *Guidance on Slope Failure Mechanisms and Stability Hazard Assessment* report, updated in 2024 (Reference 3; included as **Attachment D**). The slope stability correlations, also known as the FOS Tool, are based on a parametric analysis of slope stability failure potential evaluated by varying the first four questions of the Bank Stability Inspection Checklist and Bank Stability Scorecard responses:

- Slope angle expressed as the ratio (H:V) of horizontal to vertical distance (x-axis);
- Height of the slope (y-axis);
- Dominant soil type (clay or sand); and
- Relative consistency (soft, stiff, dense, loose).

The analyses produced a series of safety factor curves specific to a variety of site conditions that are now used to evaluate the potential slope stability at the crossing site. The slope stability analyses were based on post-flood, RDD where the groundwater surface remains higher than the normal stage. Analyses were performed in accordance with the United States Army Corps of Engineers (USACE) *Engineering Manual (EM) 1110-2-1902 Slope Stability* (Reference 2). Wet sandy soil materials were evaluated as saturated using excess pore pressure methods to conservatively consider flow slides of liquefiable sands as the design failure mode. These conservative assumptions were applied to the following six soil conditions:

- Stiff Fat Clay
- Stiff Lean Clay
- Soft Fat Clay
- Soft Lean Clay
- Loose Saturated Sand
- Dry Dense Sand.

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The resulting FOS graphs for the selected soil types and consistencies have been separated by color indicating ranges of FOS and the potential for slope failure of banks with corresponding geometry. The colors represent the slope stability categories of the Bank Stability Scorecard as shown in Table 3. Lower FOS signify that the driving forces are almost equal to the resisting forces and action is required to either collect additional data to confirm the results or begin design of mitigation. The frequency of monitoring slopes is based on the stability rating, with unstable slopes needing frequent observations or instrumentation. Monitoring is also based on the frequency of bank full conditions. Conditionally stable is when the FOS falls between unstable and stable and implies the need for collecting additional data or implementing trigger monitoring. FOS criteria values represent the minimal acceptable FOS for slope design and public safety.

Table 3. Scorecard Stability Rating and Slope Stability FOS Criteria

Color Category	Slope Stability	Slope Failure Probability	FOS Criteria Rapid Drawdown with Saturated Slopes
Red	Very Low (Unstable)	Very Likely	<1.1
Yellow	Medium (Conditionally Stable)	Somewhat Likely	1.1 - 1.3
Light Green	High (Likely Stable)	Unlikely	1.3 - 1.5
Green	Very High (Stable)	Very Unlikely	>1.5

While the output of the FOS Tool/Bank Stability Scorecard provides a color category, the magnitude of the calculated FOS also holds physical significance. An FOS near to or less than 1 indicates that the slope is near incipient (i.e., beginning to happen or develop) failure. Therefore, slopes with FOS less than 1.1 are typically classified as being “unstable”. Bank slopes with FOS between 1.1 and 1.3 are classified as “conditionally stable”, which means that they are stable only under a narrow range of operating conditions and can easily become unstable or experience some movement if subjected to additional external loads. Bank slopes with FOS between 1.3 and 1.5 are classified as “likely stable” but uncertainty remains in the soil parameters. An FOS greater than 1.5 is typically considered “stable”.

Figure 14 shows a general schematic of RDD FOS graphs used for scoring. The actual graphs used to assign color codes are provided on Figures 15 through 20. Equations were derived for the lines separating the three FOS on the graphs as notated on the figures. These equations are used in the scoring sheet to calculate and assign the appropriate color code for bank stability based on the resulting FOS. The color codes are carried through the evaluation and risk assessment process and may change with each iteration as additional data is collected and reviewed.

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Figure 14. RDD FOS Tool Chart (illustration only, not for evaluation)

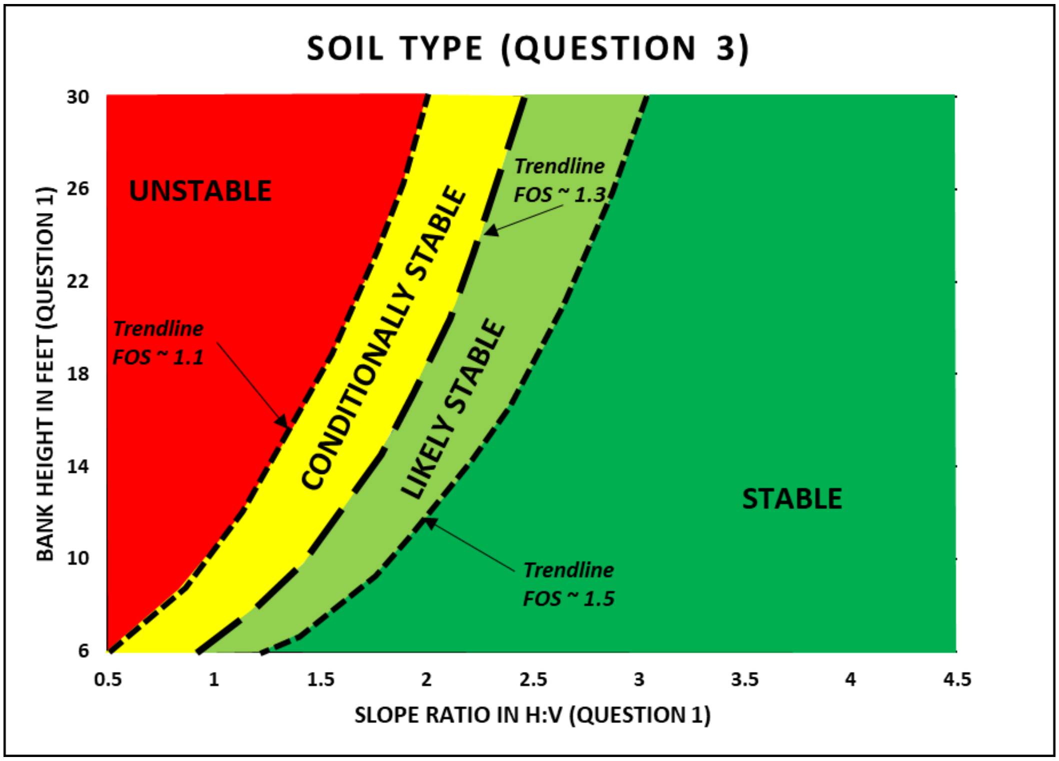

Figure 15. FOS Graph for Stiff Fat Clay

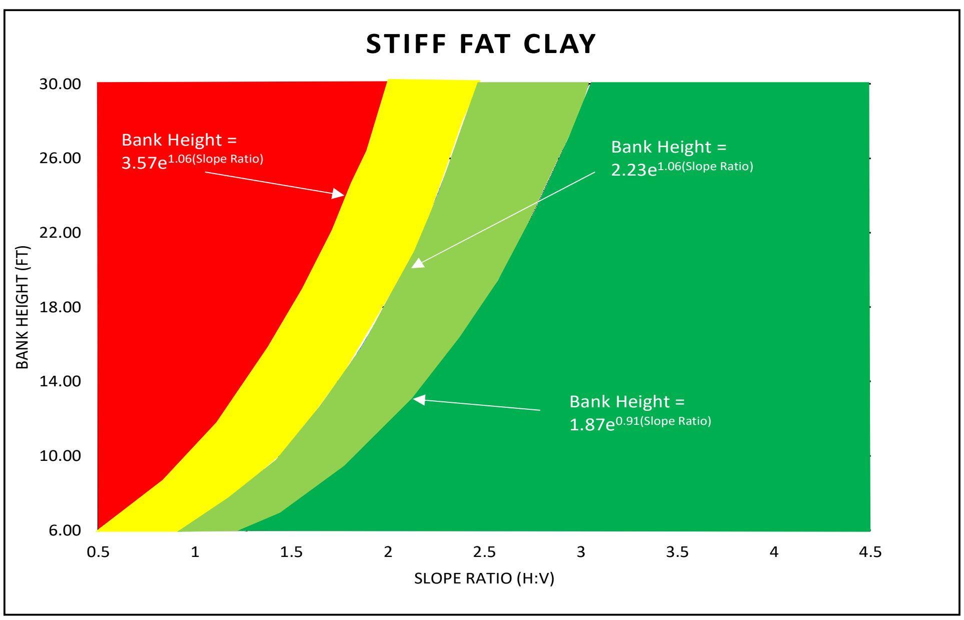

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Figure 16. FOS Graph for Stiff Lean Clay

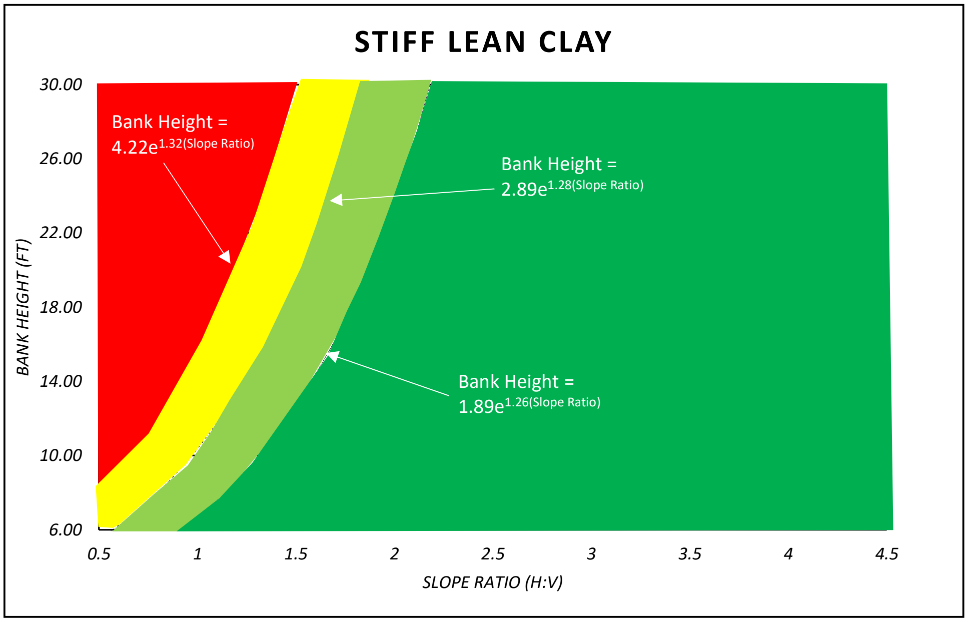

Figure 17. FOS Graph for Soft Fat Clay

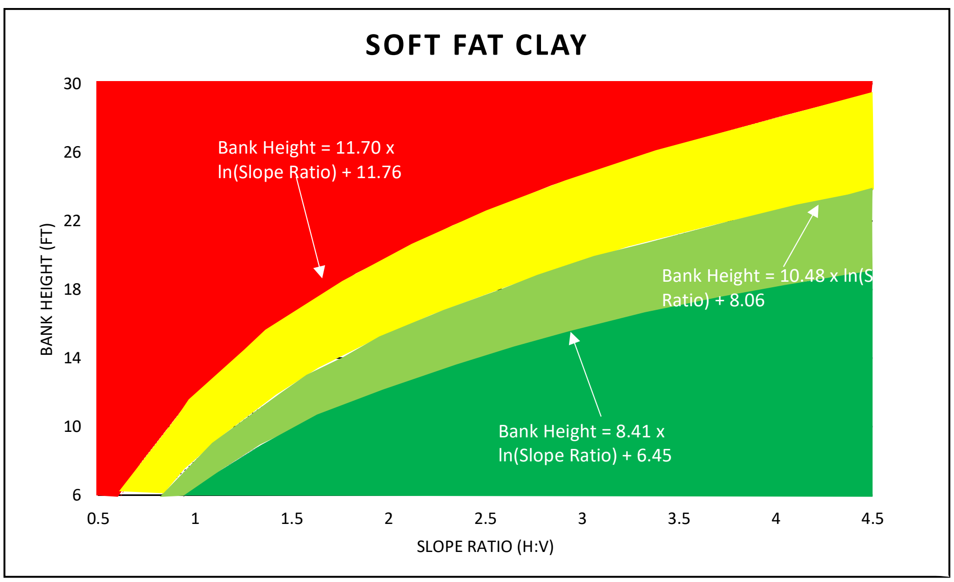

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Figure 18. FOS Graph for Soft Lean Clay

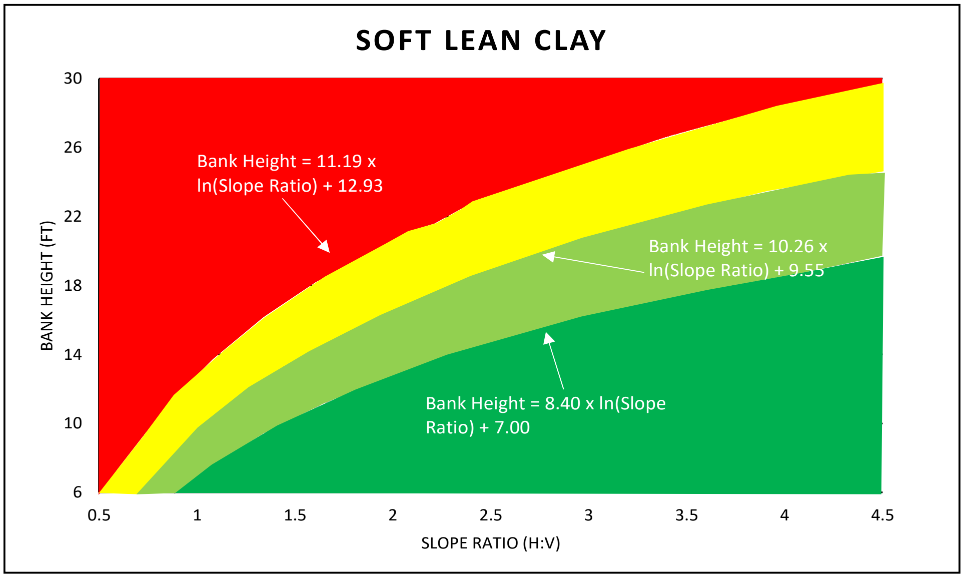

Figure 19. FOS Graph for Saturated Sand

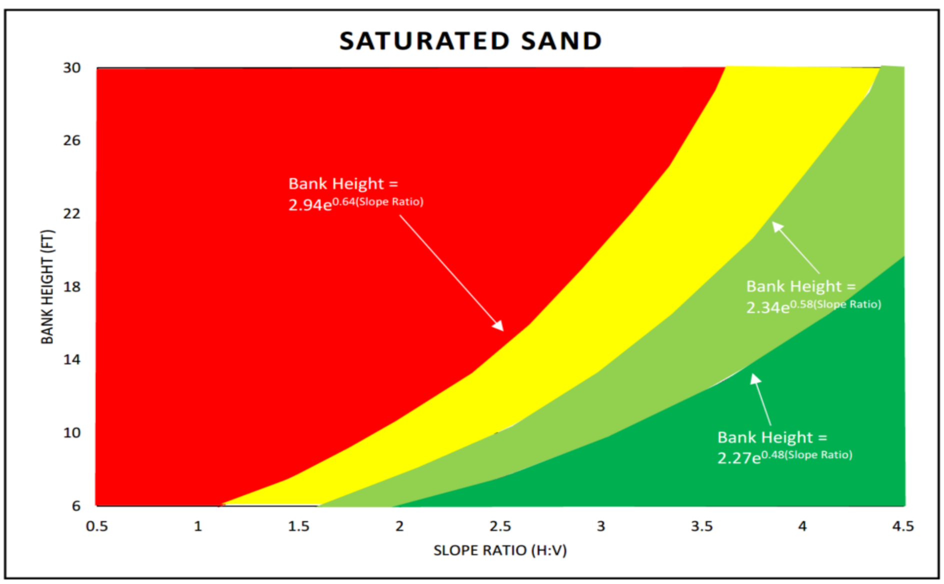

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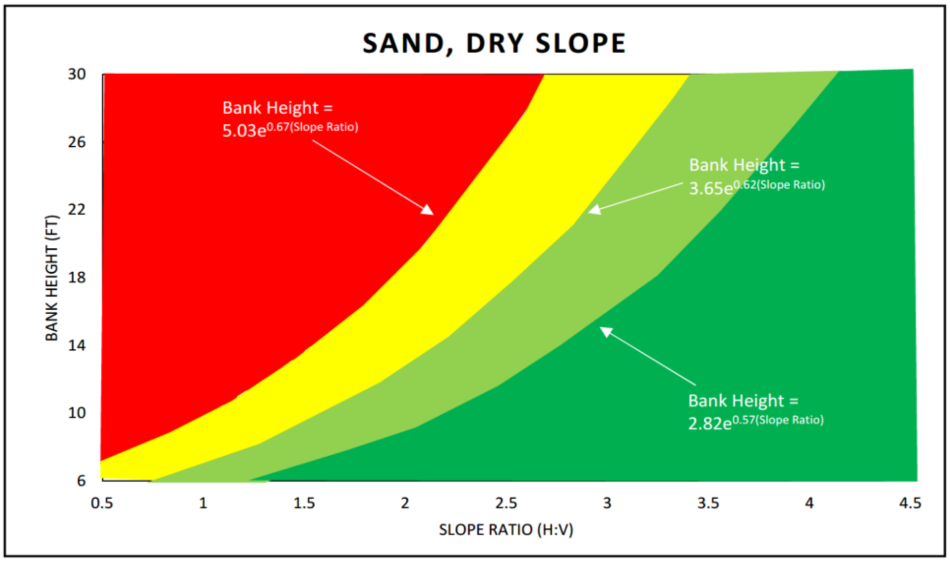
Figure 20. FOS Graph for Dry Sand



6.3 Pipeline Vulnerability

Crossings where the bank is **unstable** (red), **conditionally stable** (yellow), or **likely stable** (light green) based on FOS Tool or field inspection results should have slip surfaces drawn on their survey profiles to establish the proximity of the pipeline to a possible failure plane. Slip surfaces/failure planes are determined by finding the slope stability analysis result plate in Appendix D of the *Guidance on Slope Failure Mechanisms and Stability Hazard Assessment* report, updated in 2024 (located in **Attachment D** of this manual) that is the closest match to the bank height, slope ratio, and soil type of the water crossing. If the crossing has a red, yellow, or light green designation (i.e., FOS less than 1.5), then additional slip surface representing light-green condition (FOS less than 1.5) should also be checked, as discussed in Section 7. The slip surface is estimated by scaling the depths of several points along the slope on the figure and transferring them to the latest water crossing survey profile (if available). If a survey profile of the water crossing is not available and the SME determines that the light green, yellow, or red score is credible, then a professional survey should be requested. When the survey results become available, the Bank Stability Scorecard and failure plane should be updated accordingly.

As-built plans may be used for this step if a survey has not been performed at the time of the evaluation. The following general steps should be followed to sketch the failure surface:

1. Select the appropriate 1.5 FOS theoretical slip surface from Appendix D of the *Guidance on Slope Failure Mechanisms and Stability Hazard Assessment* report (**Attachment D** of this report) corresponding to the bank height, soil type, and slope ratio corresponding to the crossing being evaluated. An example is shown on Figure 21. The generation of the slip surfaces is described in Section 7.1.
2. From the theoretical curve selected from the *Guidance on Slope Failure Mechanisms and Stability Hazard Assessment* report, calculate the depth of the failure surface along four equidistant points along the bank length.
3. Adjusting the pdf and/or the profile to the same scale and tracing is also an option.

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4. Transfer these measurements to the survey cross section of the crossing and sketch a circular failure plane similar to the theoretical failure plane as shown on Figure 22.
5. Determine whether the pipeline falls within the estimated failure plane versus outside the plane with a buffer of at least 5 feet.

Figure 21. Example Slope Stability Figure with Theoretical Slip Surface

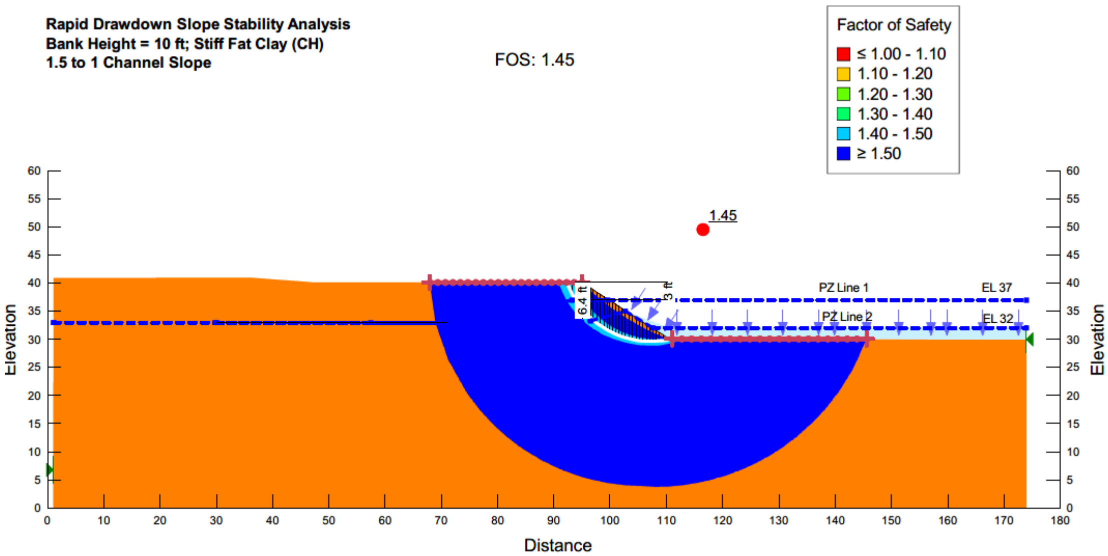
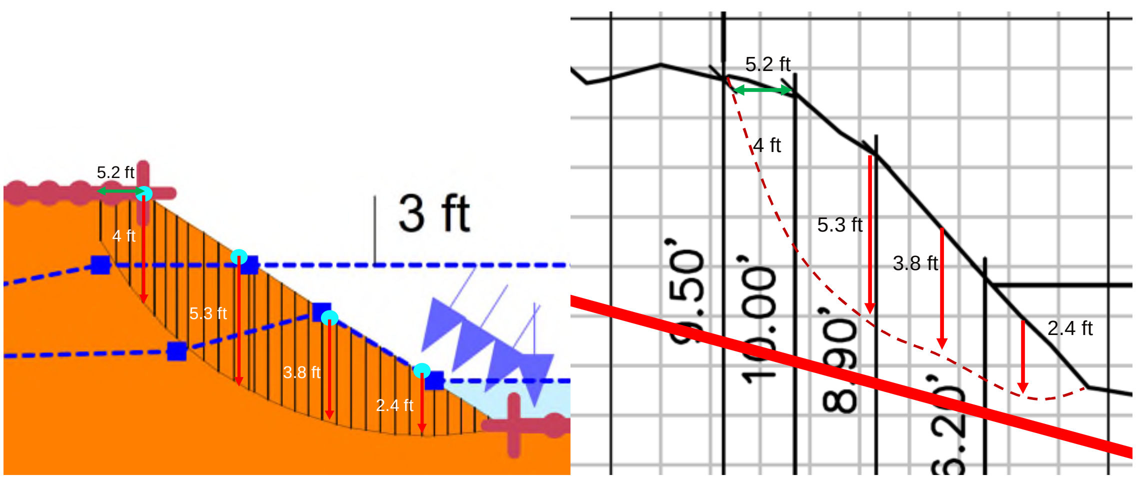


Figure 22. Example Using Four Points to Transfer Slip Surface to Profile



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6.4 Vulnerability of Elevated Pipelines

The bank stability assessment procedures also apply to pipelines suspended across a channel. In cases where pipe supports are present in the channel and/or on the bank, potential instability affects the supports by applying lateral loading to the base that may ultimately result in movement and/or tilting. Loss of a support should be compared to the allowable USL. Where no supports are present at a suspended crossing, bank erosion or slope failure may increase the unsupported length. Bank failures typically apply little load to the pipeline due to the smaller soil mass above the pipeline at the top of the slope and the short length of pipeline in the ground deformation zone.

Embedment depths of supports is usually unknown and should be assumed to be approximately 3 feet when no construction plans are available. Evaluation includes determining the distance of the 1.5 failure surface from the estimated bottom of the support piles. When the failure surface passes below the support pile tip, there is a potential for collapse of the support structure should the slope fail. If the 1.5 FOS surface intersects the pile, the pile must be able to resist the forces or movement will result. (A prescribed bank stability procedure for pipe support assessment may be developed in the near future.)

Figure 23 shows an example of an elevated pipeline with instability threatening to increase the unsupported length and/or impact the support structure depending on the failure surface. Section 5a of EMPCo Form PL-2388, External Infrastructure Inspection has a rating system based on condition of pipe supports including tilt, corrosion, connection to pipeline, and erosion/scour at base. WCEs use this form to evaluate the condition of the support(s) and the need to collect additional information.

Figure 23. Examples of Elevated Pipelines with Support Structures

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7 Slope Stability Hazard Matrix

Once the bank stability scoring sheet is complete and the final score has been reviewed by an SME, the next step of the assessment process is the Slope Stability Hazard Matrix. The matrix combines slope stability and pipeline vulnerability factors. If the crossing has a credible bank stability concern, the color categories from the Bank Stability Scorecard are used to produce the *likelihood of slope failure* on the Slope Stability Hazard Matrix. Definitions of slope failure likelihood are aligned with ExxonMobil Risk Matrix GMOP 2.1(B) - Attachment 1. The Slope Stability Hazard Matrix was developed to define slope stability hazard potential for WCP sites using the established Bank Stability Scorecard color-coded categories for potential bank failure at the crossing site. The color codes are reiterated below.

1. RED indicates unstable conditions.
2. YELLOW indicates conditionally stable conditions.
3. LIGHT GREEN indicates likely stable conditions.
4. GREEN indicates stable conditions.

The Slope Stability Hazard Matrix is shown on Figure 24 and included in **Attachment B-7**. The matrix describes the conditions that require further assessment by an SME who will establish monitoring and mitigation solutions based on thorough review of inspection documents, site visits, soil borings, and/or any other information necessary to make an accurate assessment.

The Slope Stability Hazard Matrix guides the WCEs through the action items necessary to complete the bank stability assessment at pipeline water crossings. The Slope Stability Hazard Matrix requires two inputs: slope vulnerability from the Bank Stability Scorecard color category, and pipeline vulnerability. The pipeline vulnerability input is based on calculation of sufficient pipeline setback distance from the failing bank. For example, an HDD crossing with a very wide setback and depth of cover would be deemed as “sufficient setback”. If the setback is unknown, additional data may be required such as Operational input, survey data, and geotechnical SME guidance.

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Figure 24. Slope Stability Hazard Matrix

<table>
<tr><th colspan="6">Slope Stability Hazard Matrix for Pipeline Water Crossings</th></tr>
<tr><td colspan="6">The Slope Stability Hazard Matrix uses the score from Bank Stability Scorecard (i.e., most conservative color category from the Bank Stability Inspection Checklist scoring spreadsheet/site observations and slope stability FOS chart results). The color category represents the likelihood of slope failure. The matrix also uses a pipeline vulnerability input based on calculation of sufficient pipeline setback distance and depth of cover. The output of the matrix is an action which guides the WCEs through the process of assessing bank stability at pipeline water crossings. Definitions of Slope Failure likelihood from ExxonMobil Risk Matrix GMOP 2.1(B) - Attachment 1 were used.</td></tr>
<tr><th colspan="3">Slope Vulnerability</th><th colspan="3">Pipeline Vulnerability</th></tr>
<tr><th rowspan="2">Color Category</th><th rowspan="2">Slope Stability</th><th rowspan="2">Slope Failure</th><th>Sufficient setback
(Pipeline >5 ft from Failure Planes*)</th><th>Unknown setback
(Pipeline location unknown)</th><th>Insufficient setback
(Pipeline within 5 ft of Failure Planes or Progressive Sloughing*)</th></tr>
<tr><td>Negligible</td><td>Marginal</td><td>Serious</td></tr>
<tr><td>Red</td><td>Very Low (Unstable)</td><td>Very Likely</td><td>Action 5</td><td>Action 1</td><td>Action 1</td></tr>
<tr><td>Yellow</td><td>Medium (Conditionally Stable)</td><td>Somewhat Likely</td><td>Action 5</td><td>Action 3</td><td>Action 2</td></tr>
<tr><td>Light Green</td><td>High (Likely Stable)</td><td>Unlikely</td><td>Action 5</td><td>Action 3</td><td>Action 4</td></tr>
<tr><td>Green</td><td>Very High (Stable)</td><td>Very Unlikely</td><td>Action 6</td><td>Action 6</td><td>Action 6</td></tr>
<tr><td colspan="6">*If Slope/W has not been run: “Failure Planes” is defined as critical failure plane pre-drawn in 2024 Guidance on Slope Failure Mechanisms and Stability Hazard Assessment report. If Slope/W has been run: “Failure Planes” is defined as those with FOS up to 1.5 for steady state and rapid drawdown loading.</td></tr>
<tr><th>Action #</th><th colspan="5">WCE Actions Based on Assessment</th></tr>
<tr><td>1</td><td colspan="5">Immediately engage Third Party SME to review inspection documents and professional survey, and schedule Third Party SME site visit. Notify Operations of recommended next steps, including obtaining professional survey if one is not available, following site visit. Third Party SME will run preliminary Slope/W analysis based on conservative soil assumptions and advise on need for soil borings, refined Third Party SME Slope/W assessment, and interim trigger monitoring or HWAP. Assess the structural condition/capacity of the pipe vs. predicted strain demand (run Soil Springs). Assess for bank stability threat per Third Party SME guidance, request review by ExxonMobil SME, and risk assess as needed. Based on risk assessment results, consider operational controls including HWAP and engineering controls or pipe reroute as needed. Assign scheduled monitoring frequency and trigger monitoring per Third Party/ExxonMobil SME input.</td></tr>
<tr><td>2</td><td colspan="5">Engage Third Party SME to review WCE inspection documents and professional survey and confirm that Third Party SME site visit is needed. Third Party SME will run preliminary Slope/W analysis based on conservative soil assumptions and advise on need for soil borings, refined Third Party SME Slope/W assessment, and interim trigger monitoring or HWAP. Assess the structural condition/capacity of the pipe vs. predicted strain demand (run Soil Springs). Assess for bank stability threat per Third Party SME guidance, request review by ExxonMobil SME, and risk assess as needed. Based on risk assessment results, consider operational controls including HWAP and engineering controls as needed. Assign scheduled monitoring frequency and trigger monitoring per Third Party/ExxonMobil SME input.</td></tr>
</table>

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3	Request professional survey and consider WCE site visit as needed to finalize Bank Stability Inspection Checklist inputs. Assign trigger monitoring in interim as needed. Update score card based on site visit. Third Party SME shall run preliminary Slope/W analysis based on conservative soil assumptions to determine whether the pipeline is located within failure planes with FOS up to 1.5 for RDD loading or Steady State loading condition. Re-plot crossing in the Slope Stability Hazard Matrix based on updated pipeline vulnerability and evaluate the need for soil boring to eliminate conservatism from Slope/W analysis as needed.
4	If insufficient setback was determined based on overlay with pre-populated critical failure plane from the 2024 *Guidance on Slope Failure Mechanisms and Stability Hazard Assessment* report, then: • Third Party SME shall complete preliminary Slope/W analysis based on conservative soil assumptions to determine whether the pipeline is still located within failure planes with FOS <1.5 for RDD or Steady State condition. Re-plot crossing in the Slope Stability Hazard Matrix based on updated pipeline vulnerability and evaluate the need for soil boring to eliminate conservatism from Slope/W analysis as needed. If insufficient setback was determined based on Slope/W analysis: • Consult with ExxonMobil geotechnical SME to assess the structural condition/capacity of the pipe vs. predicted soil loading (run Soil Spring) and risk assess crossings that are predicted to exceed pipeline limitations. Consult with ExxonMobil geotechnical SME when risk assessing and provide SME with Slope/W analysis and Soil Spring results to aid in determination of probability that soil loading will exceed pipeline limitations and result in loss of containment. • Assign scheduled monitoring and trigger monitoring per Third Party SME input.
5	If sufficient setback was determined based on survey overlay with pre-populated critical failure plane from the 2024 *Guidance on Slope Failure Mechanisms and Stability Hazard Assessment* report, then: • Third Party SME shall run preliminary Slope/W analysis based on conservative soil assumptions to determine whether the pipeline is located within failure planes with FOS up to 1.5 for RDD or Steady State loading condition. Re-plot crossing in the Slope Stability Hazard Matrix based on updated pipeline vulnerability and evaluate the need for soil boring to eliminate conservatism from Slope/W analysis as needed. If sufficient setback was determined based on Slope/W analysis: • Assign scheduled monitoring and trigger monitoring per Third Party SME input. • For crossings with red/unstable or yellow/conditionally stable bank score, review recommendations with ExxonMobil SME and discuss whether Scenario Based Risk Assessment should be performed to capture potential threats associated with future progressive bank failure.
6	Assign scheduled monitoring and trigger monitoring per WCP guidelines.

7.1 Bank Stability Assessment (Geotechnical Investigation and Slope/W)

According to the output of the Slope Stability Hazard Matrix (Figure 24), bank stability assessment using Slope/W software may need to be performed to better estimate whether the pipeline is located within predicted bank failure planes with FOS up to 1.5 and/or to update the analysis after acquiring on new soil information or back-calculate soil parameters based on observed instability. The Slope/W assessment is performed by a Third Party SME or Engineer with at least 5 years of Slope/W experience who is supervised by an SME.

WCEs shall provide the Third Party SME with the following inputs to support the Slope/W model:

- Survey profile of the ground surface and pipeline, preferably as x, y coordinates in an Excel spreadsheet;

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- Groundwater/surface water levels based on soil saturation and hydrology data (if available);
- Soil borings, geotechnical and lab test reports and any previously collected soil data if available;
- Maps or photos that show existing cracking or slope instability features, if any; and
- Hydrology assessment data for normal water level and water elevations for the range of flood frequency events, when available.

It should be noted that the Third Party geotechnical SME should be responsible for the interpretation of soil stratigraphy and soil strength parameters from available data.

Slope/W utilizes the above inputs and Spencer's method of analysis in accordance with USACE Slope Stability Manual EM 1110-2-1902 to build a two-dimensional model of the bank slope and failure surfaces for RDD and normal/low water level loading.

The critical scenario of RDD is modeled with banks saturated up to the flood level while the stream is at its post-flood lower level (which is why there are two water surfaces in RDD models for clayey soils). SLOPE/W locates the critical failure surface with the lowest FOS using an iterative search routine in combination with search criteria imposed by the user. The Failure Surface with FOS equal to 1.5 is also plotted, along with a few additional failure surfaces with FOS between 1.5 and critical FOS, depending on the difference between FOS values.

Guidance on Slope Failure Mechanisms and Stability Hazard Assessment (Reference 3; included as **Attachment D**) has full description of analyses including sands with elevated pore pressures.

To support bank stability assessment, the WCE may be responsible for providing additional data including hydrographs from USGS gages, historical storm events, and flood frequency if available. The hydrographs should include estimates of how many bankfull saturation events have occurred in the past 10 years. If the aforementioned information is needed, it will be requested by the Third Party geotechnical SME building the SlopeW model. If a geotechnical investigation is necessary, the SME will develop a drilling plan that includes the required soil boring locations, depths, and laboratory tests.

The results of the SME assessment will be summarized in a Bank Stability Assessment Report that contains the following, at a minimum:

1. Summary of site conditions and observations regarding bank stability;
2. Data collected during the geotechnical investigation such as interpreted soil profiles and properties;
3. Slope geometry and location/alignment of modeled cross section relative to the bank and pipeline crossing;
4. Results of the site-specific slope stability analyses performed for both steady state (LWL or NWL) and RDD scenarios;
5. Recommended soil parameters, including friction angle and undrained shear strength, for use in pipeline structural analysis (i.e., Soil Springs Excel spreadsheet used to calculate soil forces predicted to act on the pipeline); and
6. Conclusions and recommendations for further assessment, monitoring, and/or a concept mitigation approach.

An ExxonMobil SME will review all bank stability assessment reports for unstable and conditionally stable crossings and provide comments to the WCE. The WCE should keep the ExxonMobil SME informed of progress and scope of work recommended for these crossings throughout the process.

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8 Structural Evaluation of Pipeline in Failure Zone

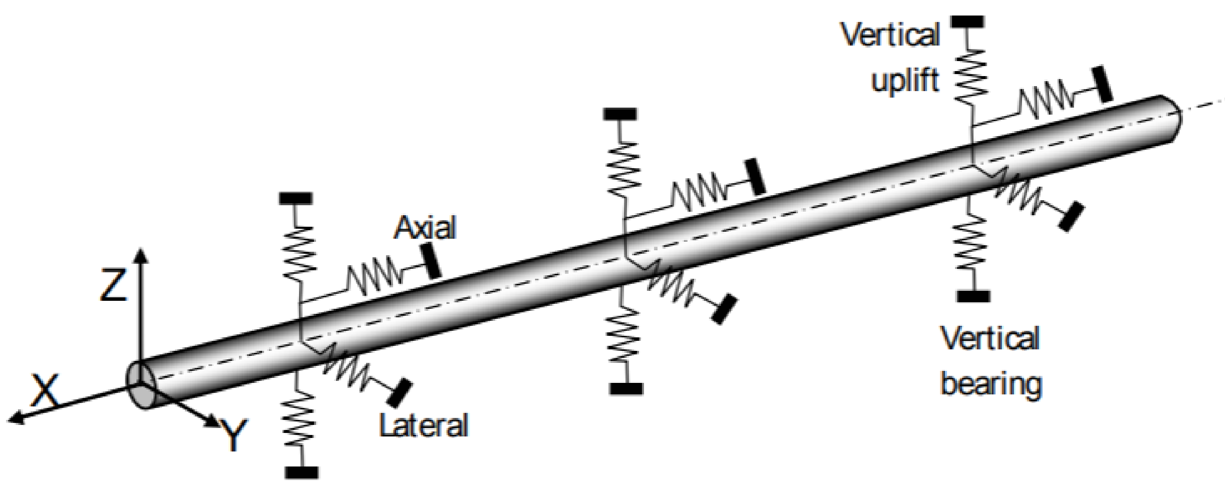
Actions 1, 2, and 4 of the Slope Stability Hazard Matrix indicate an assessment of the structural capacity of the pipeline versus the estimated stress demand of the potential failure surface should be calculated. Currently, the WCP uses Soil Springs Excel workbook as one method to calculate predicted versus allowable length of pipe in failure plane based on soil and pipe parameters from the Bank Stability Assessment (Slope/W). Crossings that are predicted to exceed allowable limitations should be risk assessed. However, consult an ExxonMobil geotechnical SME before filtering out a crossing for risk assessment based on results of Soil Spring analysis.

The following paragraphs describe the basis of the Soil Spring calculations, and an overview of the Soil Springs Excel spreadsheet and corresponding formulas used in the calculations which are provided in **Attachment A Soil Spring / Permanent Ground Deformation Calculations**. The program is currently evaluating alternative methods for estimating strain demand on the pipeline due to soil movement. This procedure will be updated accordingly based on the outcome of that evaluation.

Methods for evaluating the effect of a bank failure acting upon a pipeline are based on the 1984 spring model that represents the interaction between soil and buried pipes. This method was introduced by the American Society of Civil Engineers (ASCE) in *Guidelines for the Seismic Design of Oil and Gas Pipeline Systems* (Reference 4). The ASCE model describes the pipe-soil interaction along the axial and lateral directions of the pipeline with a group of bilinear springs. An improved version of the ASCE model was later published in *Guidelines for the Design of Buried Steel Pipe* by American Lifelines Alliance in 2001 (Reference 5). The ASCE modeling methods are used to develop a general calculation of forces acting on the pipe and the length of pipe within the slope stability failure, relative to the allowable strain length determined by the pipeline properties in accordance with applicable codes and regulations.

The ASCE model adapts a bilinear relationship. Instead of shear stress and shear strain, the ASCE model describes the pipe-soil interaction through the maximum soil force applied per unit length of the pipe and the critical relative displacement between the pipe and the soil when the maximum soil force is just reached. The soil forces and the critical relative displacements are provided in three directions as shown on Figure 25.

Figure 25. Idealized Representation of Soil with Discrete Springs



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Permanent ground deformation (PGD) generally refers to irrecoverable soil displacement due to faulting, landslide, settlement or liquefaction induced lateral spreading. In this context attention is restricted to permanent soil deformation due to bank slope failure. The pipeline may cross the PGD zone in any direction; however, to simplify the approach the response of the pipeline should be analyzed as two distinct cases – parallel or perpendicular crossings. Figures 26, 27, and 28 illustrate different orientations of pipelines through the PGD zone.

Figure 26. Pipeline Crossing PGD Zone in the Direction of Ground Movement.

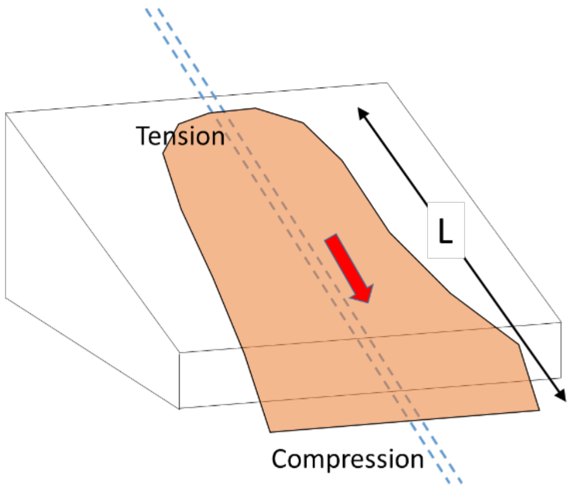


Figure 27. Pipeline Crossing PGD Zone Transverse to the Direction of Ground Movement.

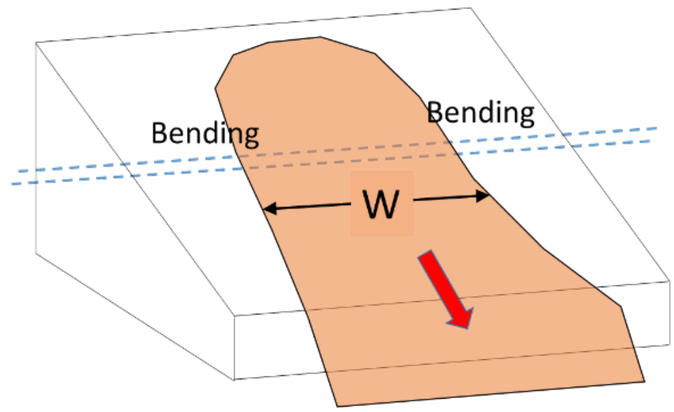
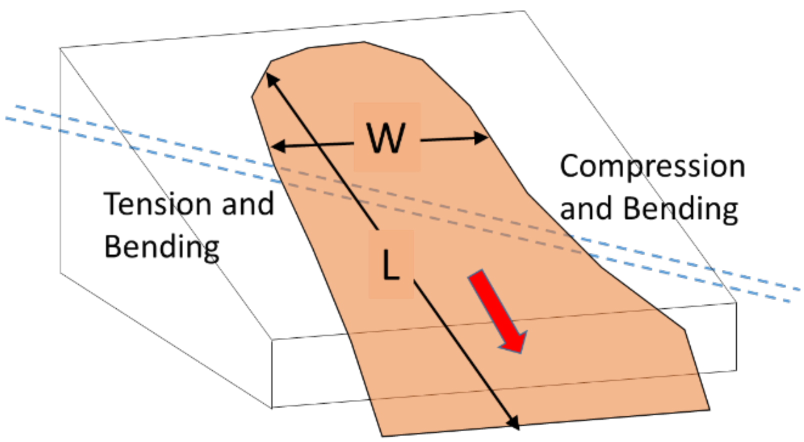


Figure 28. Pipeline Crossing PGD Zone at an Arbitrary Angle.



Pipeline profiles under water crossings may have more complex geometry (field bends). This procedure presents a simple evaluation methodology and is practically limited to consideration of initially straight pipelines, single components of lateral offset (either vertical or horizontal), constant soil-pipeline interaction parameters, and negligible pipe bending stiffness. Finite element approaches (outside the scope of this document) provide a means to investigate the effects of pipeline alignment/profile, changes in pipeline material, wall thickness, and soil characteristics (pore pressure and strength).

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9 Risk Assessment

Scenario Based Risk Assessments (SBRAs) are typically performed when the predicted failure plane that engages the pipeline has a safety factor less than 1.5 and causes stresses above the pipeline structural limitations for RDD and/or Steady State (LWL or NWL) conditions. SBRA should also be conducted when a slope failure has already been observed and has the potential to progressively expand and ultimately engages the pipe and exceeds its structural capacity limit. An SBRA meeting includes personnel from Operations, the Risk Facilitator, the WCP Technology Lead, and Lead Operations/Site Representative, the mitigation team representative, and the geotechnical SME. The WCE should create a presentation for the SBRA with the following agenda: safety moment, SBRA process overview, water crossing overview, engineering assessment, hazard identification and prioritization, and scenario development.

During the risk assessment process, the Risk Facilitator will review all possible bank failure scenarios and impacts to the pipeline. WCEs may be asked to include additional data for risk assessments. This includes hydrologic and hydraulic data used to establish a bank failure initiating event. Key points to consider are:

1. What is the most critical bank stability loading scenario identified in terms of likelihood and FOS (e.g., steady state/long-term or short-term/RDD)?
2. Is the scenario examined relevant to normal flow conditions or is it tied to/triggered by a certain return period event?
3. At what return period event do the banks become critically submerged? (SME to determine the minimum water level that could trigger an instability.)
4. How many events that could trigger RDD have been recorded in the last 5 to 10 years? (This will require review of available hydrological and gage data in the area.)
5. Are forces on the pipe predicted to exceed stress limitations?
6. What is the probable failure mechanism (i.e., rupture due to axial tension and/or bending or local buckling due to axial compression and/or bending)?
7. What is the structural condition of the pipe (e.g., corrosion, girth weld quality)?
8. Presence of other data on the pipe (e.g., IMU/ILI data) or crossing site (e.g., modification by others, drainage outlets, adjacent slope failures)?
9. If the pipeline is expected to not rupture during bank failure, is it likely to be exposed to surface water forces? If so, evaluate this pipeline length for bending in water stresses.
10. What are the estimated scour/erosion/migration rates in the channel and along the banks? Erosion of material along the slope toe may lower stability.

The WCE may find this information from the RSST outputs, other SME data for a crossing such as a scour study or similar SME guidance, USGS (or other) stream gages, and rainfall gages in the area. The WCE should coordinate with SMEs and a Risk Facilitator to help form the basis of a risk assessment with available data.

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10 High Water Action Plan and Monitoring Plan

Bank stability conditions may deteriorate from slope saturation or changes in geometry during a high water event, especially if the banks are expected to be inundated. If bank stability is a viable concern at the crossing and the crossing risk assessment suggests a heightened threat (RC1 or RC2 for RDD scenario), a HWAP should be drafted. The HWAP should focus on the most likely conditions and timing for the bank to fail, which may be well after the peak of the floodwaters. The "*HWAP Development Guide for Water Crossings*" should be referenced when developing the plan.

The Slope Stability Hazard Matrix presented on Figure 24 guides the WCE in determining frequency of monitoring for actions as outlined below:

- Slopes ranked as Action Number 1 in the matrix are of highest priority and should be monitored closely with interim trigger monitoring or a HWAP per Third Party SME and ExxonMobil guidance. Assign scheduled monitoring frequency and trigger monitoring per WCP guidelines and Third Party/ExxonMobil SME input.
- Slopes ranked as Action Number 2 are secondary and should be inspected in response to a high water event via trigger monitoring or HWAP as deemed fit by Third Party and ExxonMobil SMEs. Assign scheduled monitoring frequency and trigger monitoring per WCP guidelines and Third Party/ExxonMobil SME input.
- Slopes ranked as Action Number 3 are also secondary. Assign trigger monitoring as needed and continue scheduled monitoring.
- Slopes ranked as Action Number 4 should be inspected following a high water event. Assign scheduled monitoring and trigger monitoring per WCP guidelines or Third Party SME guidance.
- Slopes ranked as Action Numbers 5 & 6 should have the normal WCP action performed following a high water event. Assign scheduled monitoring and trigger monitoring per WCP Guidelines. For crossings with red (unstable) bank conditions or insufficient setback, the WCE should consult with the Third Party SME on scheduled monitoring and trigger monitoring frequency. For crossings with red (unstable) or yellow (conditionally stable) score, the WCE should review recommendations with the ExxonMobil SME.

During high water it may not be possible to observe or even access channels that are inundated by flooding. Crossings ranked as Action Number 1 by the matrix have the highest likelihood of experiencing a slope failure which may directly pose an increased threat (and load) to the pipeline. Therefore, Operations should carefully consider the possibility of shutting down pipeline water crossings assigned Action Number 1 during high water events. During HWAP development (based on Action Numbers 1 and 2) WCEs should reach out to the SME for guidance regarding site-specific monitoring techniques that may be considered. The SME can recommend various measures for monitoring potentially unstable slopes such as post-event inspections, professional surveying, and/or the permanent installation of surveying targets/stations or other devices. In the "Post Flood Event" scenario, the WCE should confirm with the SME whether there should be a post-flood site-specific monitoring plan.

Scheduled monitoring guidelines are summarized on a chart provided on Figure 29 and **Attachment B-8**.

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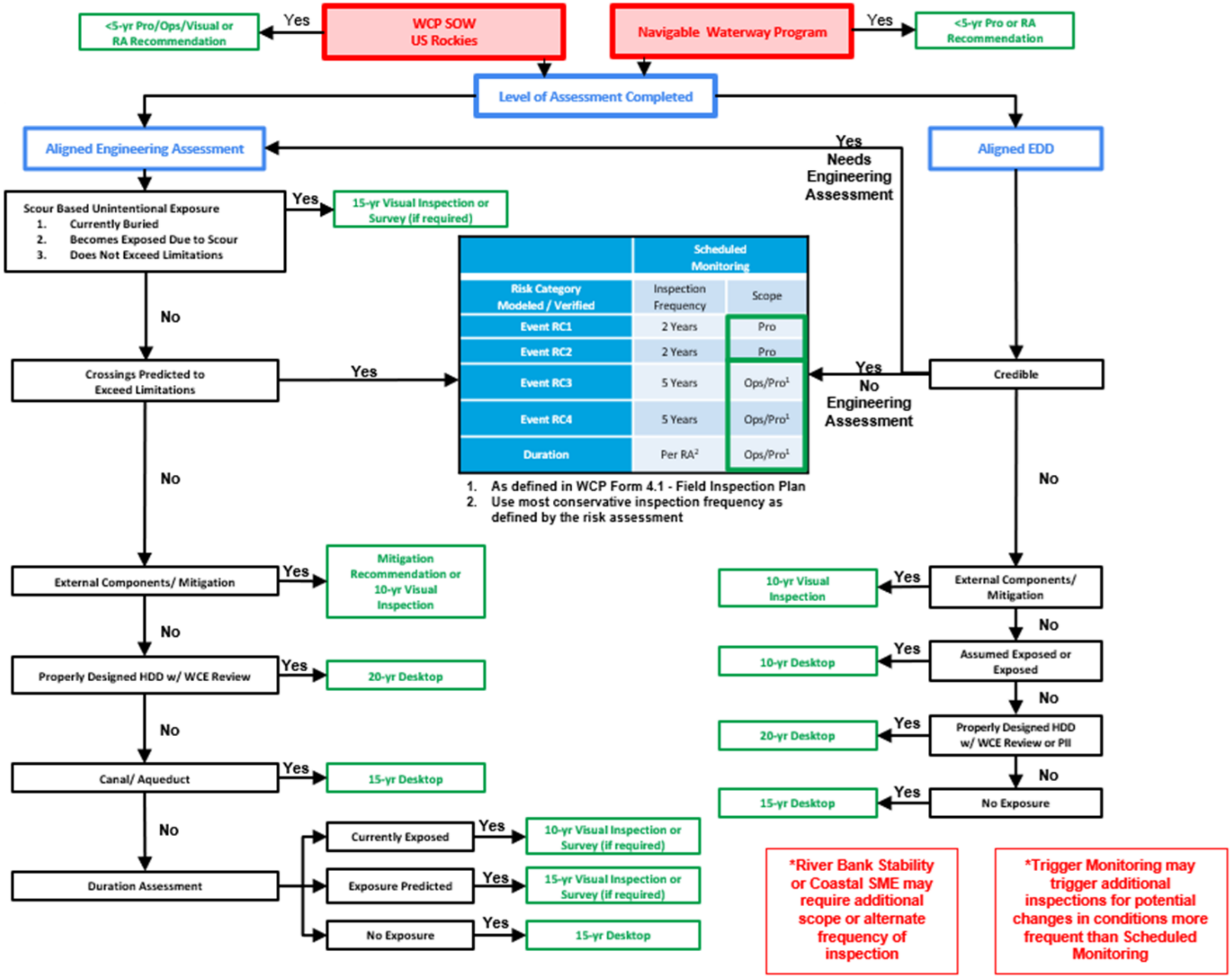
Figure 29. Monitoring Guidelines



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11 Cold Eyes Review Process

An EMPCo pipe rupture incident in 2021 triggered the need to conduct a Cold Eyes Review (CER) of “conditionally stable” and “unstable” rated pipelines. This started a review process that has become part of the program. The reviewer is typically an EMPCo SME whose work is independent of the assessments and who is not familiar with history of the subject crossings. This process can happen anytime and is usually triggered by an event or near miss where data was misinterpreted or missed entirely by the WCE screening and inspection procedures. The purpose of the CER is to reevaluate the crossings with the recent lessons learned in mind. This BSA manual includes revisions that are based on the lessons and recommendations of the 2022 CER.

The reviewer gathers all available data related to the banks and the pipeline, including risk analyses, geological information, previous stability and hydrotechnical assessments, construction plans, monitoring data, and any relevant reports. Pertinent data is summarized, observations are documented, and recommendations are summarized in a presentation. A meeting is held where the reviewer presents their findings for each pipeline crossing followed by discussion and determination of action items. CER is a valuable process that continually improves the pipeline integrity program.

12 Mitigation

The goal of mitigation is to lower the potential threat of pipeline rupture by stabilizing the slope, addressing erosion, or relocating the pipeline. Given the location of a bank slope failure that could be a threat to pipeline integrity, there are two options:

1. Take <u>engineering</u> steps to eliminate the hazard (grading, slope reinforcement, drainage, replacing soil over and at the pipeline, increase pipe strength); or
2. Take <u>operational</u> steps to limit impact to pipeline (pipeline relocation).

Slope stabilization methods generally consist of combinations of:

a. Increasing soil resistance forces through changes in drainage;
b. Reducing driving forces through grading to a milder slope; or
c. Providing additional external resistance through retaining walls, toe buttressing, sheet piles, bulkheads or soil anchors.

For shallow failures, relocating the pipe beneath the unstable area can be accomplished using conventional trenching methods. HDD techniques can be utilized to place a pipeline below a deeper failure surface or to sufficiently set it back from an unstable bank. When long-term slope instability is caused by bank erosion, bank/scour protection can be a supplemental measure to prevent the downstream migration of the soils.

The WCE will work with Operations, geotechnical SMEs, and the mitigation team to determine the approach that will best stabilize the bank for the long term. The October 2015 Arcadis memo titled “Water Crossing Mitigation Guide for Channel Armoring and Bank Protection” (Reference 6) should be reviewed for applicable solutions. Slope stability analyses should be run by the SME for the proposed mitigation scenarios to confirm that FOS criteria are met. Once the team agrees on a mitigation plan, the Bank Stability Report should be updated to include analyses of the mitigated slope and pipeline. A description of the mitigation concept with sketches should be added to the report which is reviewed before implementation of the measures.

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Periodic monitoring is required for any mitigation method. The specific types of data to be collected and the monitoring frequency are highly dependent upon the type of mitigation measures and the relative potential for adverse slope failure conditions. The development and periodic review of a monitoring plan is an essential component of the overall mitigation effectiveness. Follow-up inspections may be necessary to confirm the reestablishment of vegetation and the absence of additional erosion in the areas disturbed by construction.

13 References

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Glossary

Depth of cover	DOC is the measured quantity of sediment/soil between the top of pipe elevation and the overlying ground elevation.
Erosion	Erosion is the process by which soil and rock are removed from the Earth's surface by natural forces such as water flow and then transported and deposited in other locations.
Factor of Safety (FOS)	In the context of slope failure, FOS is the ratio of the resisting forces to driving forces.
High Water Action Plan (HWAP)	HWAPs identify systems, facilities, and resources that could be affected during a high water event and outline escalating response actions based on regulatory guidance and American Petroleum Institute Recommended Practice 1133 *Guidelines for Onshore Hydrocarbon Pipelines Affecting High Consequence Floodplains*.
Live loads	Loads that can vary during the life of an embankment such as water loads, temporary structure and vehicle weight etc.
Permanent Ground Deformation (PGD)	PGD generally refers to irrecoverable soil displacement due to faulting, landslide, settlement or liquefaction induced lateral spreading. In this document, PGD is limited to permanent soil deformation due to bank slope failure.
Pipe protection	Material placed along the channel bottom and/or channel banks or around the pipe itself to protect the pipe from damage.
Pipe supports	A device designed to carry the weight of the pipe, any in-line equipment, and the material in the pipe over a defined span.
Rapid Drawdown (RDD)	A bank becomes inundated long enough that the soil becomes saturated, and water recedes so quickly that the bank is still saturated after the waterbody is at normal water levels.
Scour	The removal of sediment such as sand and rocks from a specific area of the water body.
Seepage	Seepage is the movement of water in soils. Seepage depends on several factors, including permeability of the soil and the pressure gradient.
Shear strength	Shear strength is used to describe the magnitude of the shear stress that a soil can sustain. The shear resistance of soil is a result of friction and interlocking of particles, and possibly cementation or bonding at particle contacts.
Slip surface	Discrete surface where shear movements may occur. May also be called failure surface.
Sliding	A shear failure in which a surficial portion of the embankment moves downslope. If such failure becomes progressively larger, it may represent a threat to embankment stability.

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Soil consistency	The strength with which soil materials are held together or the resistance of soils to deformation and rupture.
Stable banks	Stable banks are identified by lack of erosion at the pipeline water crossing. Often identified by well vegetated banks.
Unsupported span length (USL)	The length of pipe that is not in direct contact with either a pipe support or bedding material.
Water Crossing Inventory	Stores information about water crossings. WCP participants should update the Water Crossing Inventory upon completion of each phase of the Water Crossing Program work process flow.

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Acronyms and Abbreviations

ASCE	American Society of Civil Engineers
BTC	Bangalore Technology Center
CER	Cold Eyes Review
EM	Engineering Manual
EMPCo	ExxonMobil Pipeline Company
ExxonMobil	ExxonMobil Corporation
FOS	factor of safety
GIS	Geographic Information System
H:V	horizontal to vertical
HWL	high water level
HWAP	High Water Action Plan
LWL	low water level
NWL	normal water level
PGD	permanent ground deformation
RDD	rapid draw down
RSST	Rapid Scour Screening Tool
SBRA	Scenario Based Risk Assessment
SME	Subject Matter Expert
USACE	United States Army Corps of Engineers
USGS	United States Geological Survey
USL	unsupported span length
WCE	Water Crossing Engineer
WCP	Water Crossing Program
WME	Water Mitigation Engineer

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Attachment A

Soil Spring / Permanent Ground Deformation Calculations

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Soil Spring / Permanent Ground Deformation Calculations

Companion to the Bank Stability Assessment Manual
Water Crossing Program Technical User Guide Support Material

Revision 1 | December 2024

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Revision Record

Revision No.	Date Issued	Reviewed By	Description
0	2.2022	EMPCo	Developed soil spring and permanent ground deformation calculations in support of bank stability assessment methodology for the Water Crossing Program.
1	12.2024	Svetlana Shafrova, EMTech	Minor text edits.

Relevance

These soil spring and permanent ground deformation calculations are an attachment to the *Bank Stability Assessment Manual*, which is a companion to the Water Crossing Program Technical User Guide.

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Contents

Tables

Figures

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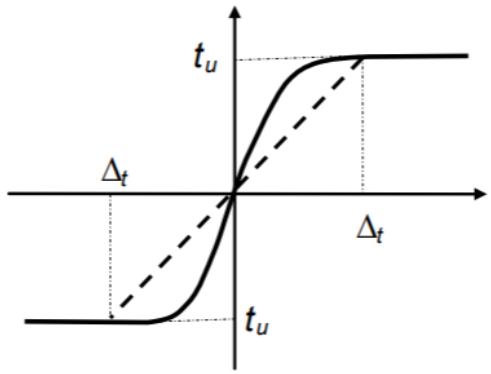
1 Axial Soil Spring

The axial soil spring represents soil resistance over the pipe surface along its length (Figure 1). The properties of axial soil springs are estimated by considering the soil properties of the backfill material used in the trench, if known, or the predominant soil type based on boring logs.

Figure 1. Soil Springs Used to Represent Axial Force on Pipe and Bilinear Idealization



The maximum axial soil resistance per unit length of pipe can be calculated as shown in Equation 1:

$$t_u = \pi D c \alpha + \pi D H \bar{\gamma} \left(\frac{1+K_O}{2}\right) tan\delta \qquad \text{Equation 1}$$

Where:

- D = Outside diameter of pipe.
- c = Coefficient of cohesion of backfill soil.
- H = Depth of soil above the center of the pipeline.
- $\bar{\gamma}$ = Effective unit weight of soil.
- α = Adhesion factor.
- δ = Interface angle of friction between pipe and soil; δ= f φ (see Table 1).
- φ = Internal friction angle of the soil.
- f = Friction factor for various types of pipes.
- K_o = Coefficient of soil pressure at rest. K_o= 1-sin(φ).

Table 1. Friction Factor for Various Types of Pipes

Pipe Coating	*f*
Concrete	1.0
Coal Tar	0.9
Rough Steel	0.8
Smooth Steel	0.7
Fusion Bonded Epoxy	0.6
Polyethylene	0.6

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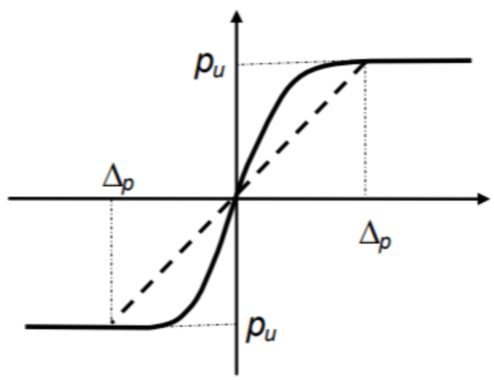
The maximum soil force along the pipe axial direction is t_u and the critical relative displacement reaching t_u is Δ_t. The maximum mobilizing displacement of soil (Δ_t) in axial direction of pipe can be taken as:

- 0.1 inch for dense sand.
- 0.2 inch for loose sand.
- 0.3 inch for stiff clay.
- 0.4 inch for soft clay.

2 Lateral Soil Spring

The lateral spring represents the lateral resistance of soil to pipe movement (Figure 2). The properties of axial soil springs are estimated by considering the soil properties of the native soil at the site.

Figure 2. Soil Springs Used to Represent Lateral Force on Pipe and Bilinear Idealization



The maximum lateral resistance of soil per unit length of pipe can be calculated as shown in Equation 2:

$$p_u = N_{ch} c\, D + N_{qh} \bar{\gamma} H D \qquad \text{Equation 2}$$

Where:

N_{ch} = Horizontal bearing capacity factor for clay (0 for c = 0).
N_{qh} = Horizontal bearing capacity factor for sandy soil (0 for φ = 0).
See Table 2.

Equations 3 and 4 below are closed form fits to published empirical relations:

$$N_{ch} = a + bx + \frac{c}{(x+1)^2} + \frac{d}{(x+1)^3} \leq 9 \qquad \text{Equation 3}$$

$$N_{qh} = a + bx + cx^2 + dx^3 + ex^4 \qquad \text{Equation 4}$$

Where $x = H/D$.

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Table 2. Lateral Soil Spring Coefficients

Factor	ϕ	*x*	*a*	*b*	*c*	*d*	*e*
N_{ch}	0°	*H/D*	6.752	0.065	-11.063	7.119	--
N_{qh}	20°	*H/D*	2.399	0.439	-0.03	$1.059(10)^{-3}$	$-1.754(10)^{-5}$
N_{qh}	25°	*H/D*	3.332	0.839	-0.090	$5.606(10)^{-3}$	$-1.319(10)^{-4}$
N_{qh}	30°	*H/D*	4.565	1.234	-0.089	$4.275(10)^{-3}$	$-9.159(10)^{-5}$
N_{qh}	35°	*H/D*	6.816	2.019	-0.146	$7.651(10)^{-3}$	$-1.683(10)^{-4}$
N_{qh}	40°	*H/D*	10.959	1.783	0.045	$-5.425(10)^{-3}$	$-1.153(10)^{-4}$
N_{qh}	45°	*H/D*	17.658	3.309	0.048	$-6.443(10)^{-3}$	$-1.299(10)^{-4}$

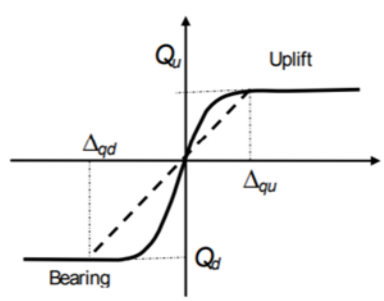
For the lateral direction to the pipe in the horizontal plane, the maximum soil force is p_u and the critical relative displacement is Δ_p. The mobilizing displacement Δ_p at p_u is taken as:

$$\Delta_p = 0.04\left(H + \frac{D}{2}\right) \leq 0.01D \text{ to } 0.02D \qquad \text{Equation 5}$$

3 Vertical Soil Springs

Soil spring properties are different for uplift vs. vertical cases. The vertical bearing spring represents the vertical resistance of soil at the bottom of the pipe, while the vertical uplift spring represents the resistance at the top of the pipe (Figure 3). For vertical bearing soil spring, the properties of native soil at the site may be used. However, for vertical uplift soil spring, the properties of backfill soil are to be considered.

Figure 3. Soil Springs Used to Represent Vertical Force on Pipe and Bilinear Idealization



For the lateral direction in the vertical plane, the soil forces are Q_u and Q_d to resist the uplifting and downward movement of the pipe, respectively. The critical relative displacements are Δ_{qu} and Δ_{qd}, respectively.

3.1 Vertical Uplift

The maximum soil resistance per unit length of pipe can be calculate as shown in Equations 6, 7, and 8:

$$Q_u = N_{cv}cD + N_{qv}\bar{\gamma}HD \qquad \text{Equation 6}$$

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Where:

N_{cv} = Vertical uplift factor for clay (0 for c = 0).
N_{qv}= Vertical uplift factor for sand (0 for φ = 0).

$$N_{cv} = 2\left(\frac{H}{D}\right) \leq 10, \text{ applicable for } \frac{H}{D} \leq 10 \qquad \text{Equation 7}$$

$$N_{qv} = \left(\frac{\phi H}{44D}\right) \leq N_q \qquad \text{Equation 8}$$

The mobilizing displacement Δ_{qu} at Q_u can be taken as:

- 0.01H to 0.02H for dense to loose sands < 0.1D.
- 0.1H to 0.2H for stiff to soft clay < 0.2D.

3.2 Vertical Bearing

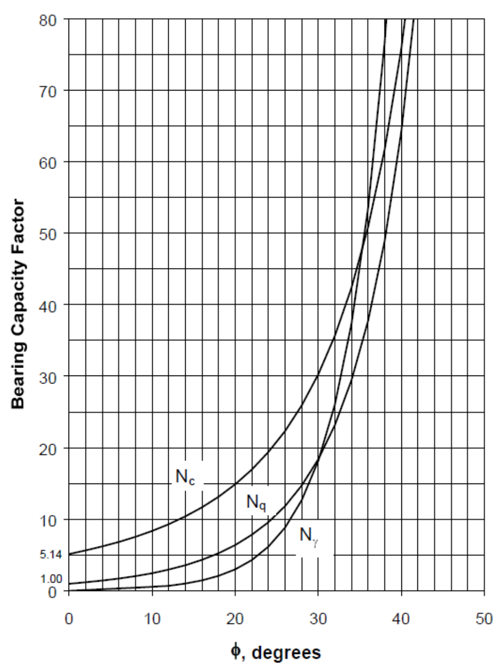
The maximum soil resistance per unit length of pipe can be calculate as shown in Equation 9:

$$Q_d = N_c cD + N_q \bar{\gamma} HD + N_\gamma \gamma \frac{D^2}{2} \qquad \text{Equation 9}$$

Where:

N_c, N_q and N_γ are bearing capacity factors from Figure 4 below:

Figure 4. Bearing Capacity Factors



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The mobilizing soil displacement Δ_{qd} at Q_d can be taken as:

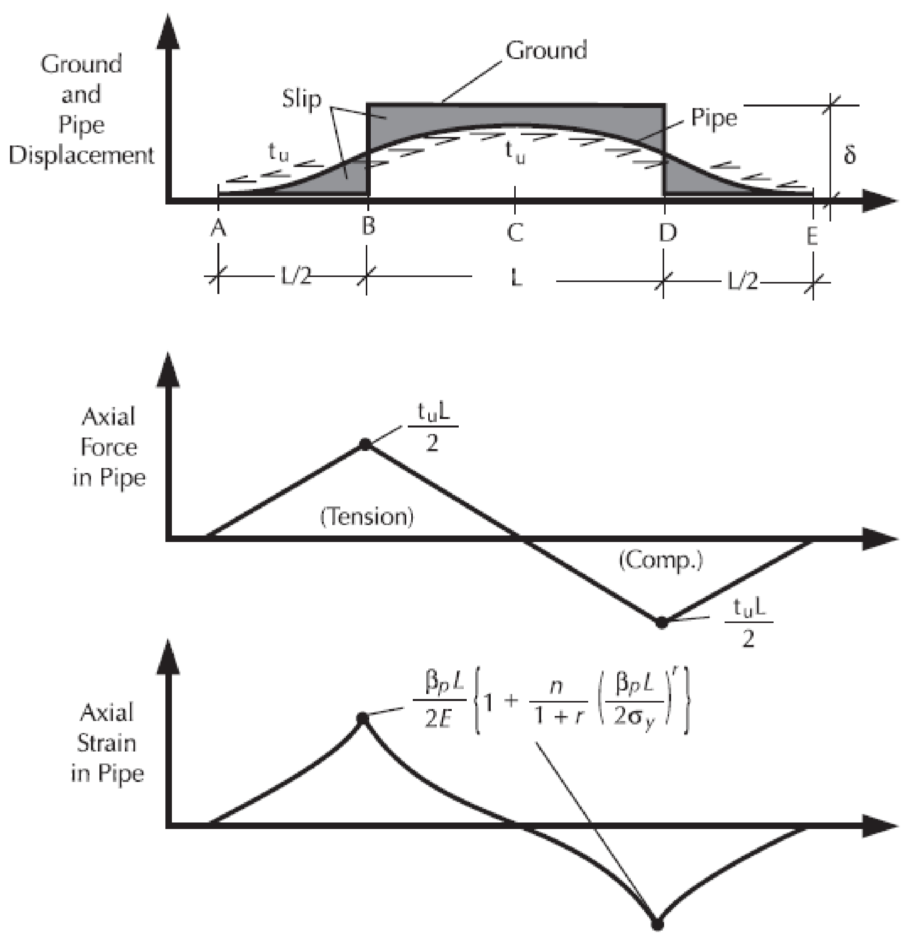
- 0.1D for granular soils.
- 0.2D for cohesive soils.

4 Longitudinal Ground Displacement

Two cases of models are used for buried pipelines as suggested by O'Rourke et al. (1995)[1]:

- Case I: The amount of ground deformation is large enough and the pipe strain is controlled by the length (L) or width (W) of the permanent ground deformation (PGD) zone (see Figure 5).
- Case II: The length (L) or width (W) of the PGD zone is large and the pipe strain is controlled by the amount of ground displacement δ.

Figure 5. Distribution of Pipe Axial Displacement, Case I (O'Rourke 1995)



[1] O'Rourke, M.J., X. Liu, and R. Flores-Berrones. 1995. Steel Pipe Wrinkling due to Longitudinal Permanent Ground Deformation. Journal of Transportation Engineering, Volume 121, Issue 5. https://doi.org/10.1061/(ASCE)0733-947X(1995)121:5(443).

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When assessing the geotechnical stability of a slope it is difficult to determine the Quantity of displacement in the failing soil mass, whereas determining the spatial extent of permanent deformation can be more straightforward. The methodology presented below is based on the assumption that Case 1 is typically more relevant to slope failure for banks assessed by the Water Crossing Program.

The maximum axial strain in the pipe for both tension and compression can be calculated as shown in Equation 10:

$$\varepsilon_a = \frac{t_u L}{2\pi D t E}\left[1 + \frac{n}{1+r}\left(\frac{t_u L}{2\pi D t \sigma_y}\right)^r\right] \qquad \text{Equation 10}$$

The first term inside the bracket accounts for elastic strain (prior to yield). The second term in the bracket accounts for elastic strain (after yielding). To remain within operating codes, the pipe should not experience yielding.

Where:

L = Length of PGD zone.
σ_y = Yield stress of pipe material.
n,r = Ramberg-Osgood parameter (see Table 3).

Table 3. Ramberg-Osgood Parameters

Pipe Grade	Yield Stress (pounds per square inch)	n	r
Grade B	35,000	10	100
X-42	42,000	15	32
X-52	52,000	9	10
X-60	60,000	10	12
X-70	70,000	5.5	16.6

E = Modulus of elasticity of pipe material.
t_u = Peak friction force per unit length of pipe at soil pipe interface.
D = Outside diameter of pipe.
t = Wall thickness of pipe.

5 Transverse Ground Displacement

When subjected to transverse ground displacement, a pipeline will stretch and bend to accommodate . The analytical expression used is based on O'Rourke's simplified model of pipeline response to transverse PGD with the conditions that: (a) the zone of ground deformation is relatively narrow; and (b) the pipe is assumed stiff.

The maximum bending strain in the pipe may be calculated as shown in Equation 11:

$$\varepsilon_b = \pm\frac{P_u W^2}{3\pi E t D^2} \qquad \text{Equation 11}$$

Where:

P_u = Maximum lateral resistance of soil per unit length of pipe.
W = Width of PGD zone.

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E = Modulus of elasticity of pipe material.
t = Wall thickness of pipe.
D = Outside diameter of pipe design.

6 Automated Excel Work Book Calculations

An Excel workbook template has been created as part of the Water Crossing Program to perform the calculations of longitudinal and transverse PGD induced stresses on a pipeline. Water Crossing Engineers use the workbook to evaluate the threat of a pipeline rupture due to slope instability. The PGD and soil profile can be determined using SLOPE/W analysis model schematics. If a SLOPE/W model is not available, then soil strength parameters must be conservatively assumed or derived from subsurface investigation data. Soil strength parameters should represent the soil layer surrounding the pipe. Pipe properties including outer diameter, wall thickness, coating, and operation pressure are required as input. An average depth of cover should be estimated based on its survey. Data necessary for the calculations are shown in Table 4.

Table 4. Workbook Input Data

Pipe Properties	Soil Properties
Pipe Outer Diameter (OD; inches)	Soil Friction Angle (φ degrees)
Pipe Wall Thickness (inches)	Soil Cohesion (c; pounds per square foot [psf])
Pipe Specified Minimum Yield Strength (SMYS; pounds per square inch [psi])	Soil Effective Unit Weight (γ'; psf)
Pipe Depth of Cover (DOC; feet)	PGD Path (perpendicular/parallel to pipe)
Length of Pipe in PGD (feet)	
Pipe Coating	
Internal Pressure (psi)	

Once the required data is entered into the proper cells on the Excel sheet, the following are calculated to determine the values of the variables needed for the pipe bending stress calculation. Calculations are based on the equations presented in this document.

- Axial soil force on pipeline
- Lateral soil force on pipeline
- Vertical bearing soil force on pipeline
- Vertical uplift soil force on pipeline.

Results of the force calculations are used to determine transverse and longitudinal strain and stress on the pipeline. The stress values are compared to allowable stress and noted as “PASS” or “FAIL” for transverse PGD and longitudinal PGD. Subject Matter Experts interprets the results and decide whether the pipeline is likely to rupture.

An example calculation performed in the Excel Workbook template is provided on the following pages (Figure 6).

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Figure 6. Example Calculation

Pipe Properties	
Pipe OD (in):	12.50
Pipe wt (in):	0.375
Pipe SMYS (psi):	X-52
Pipe DOC (ft):	6.56
Length of Pipe in PGD (ft):	473.0
Pipe Coating	Rough Steel
Internal Pressure (psi):	573

Summary Output	
Longitudinal Force (lb/ft)	1,307.5
Axial Stress (psi)	20,986.5
Remaining Allowable Stress (psi)	23,307.5
Allowable Pipe Length in PGD (ft):	525.3
Exceeds Allowable:	Does Not Exceed

Pipeline Length: FOS 1.35-1.45		Red
	143.38	m
	144.1707767	m (measurement cor
	473.0012359	ft
Pipeline Length: FOS 1.35-1.55		Red + Blue
	144.49	m
	145.29	m (measurement correction)
	476.66	ft

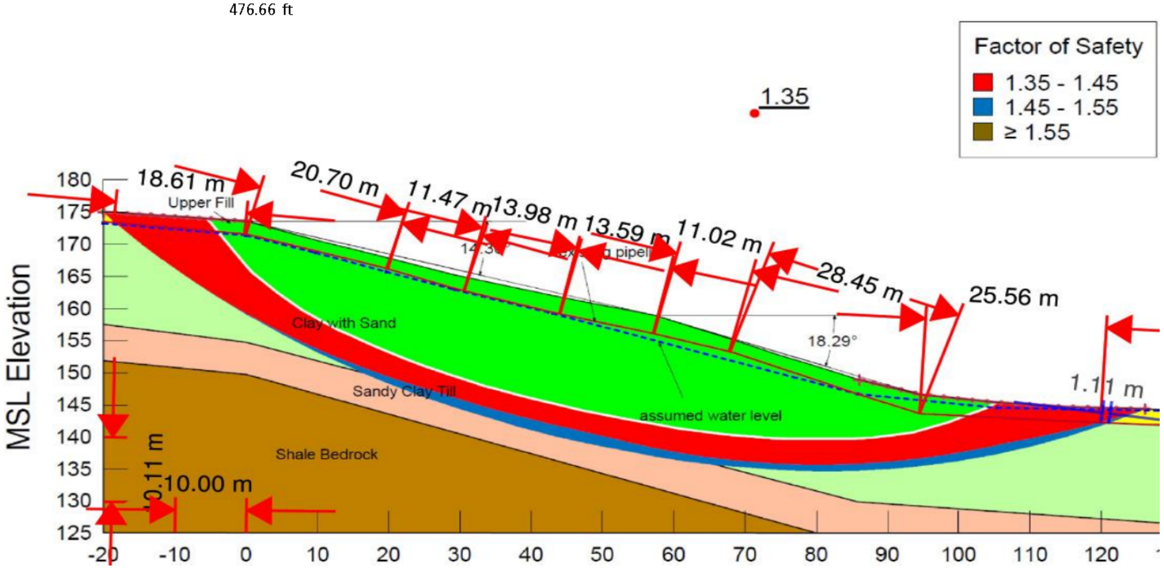
Soil Properties	
Soil Friction Angle (ϕ degrees):	27.0
Soil Cohesion (c, psf):	104.5
Soil Effective Unit Weight (γ', psf):	135.0
PGD Path (perpendicular/parallel to pipe):	Parallel

Conversions		
Cohesion: kpa		psf
	5	104.45
Unit weight: kn/m2		psf
	19	122.03917

Upper Fill	
Soil Friction Angle (ϕ degrees):	30
Soil Cohesion (c, psf):	0
Soil Effective Unit Weight (γ', psf):	
Allowable length (ft)	
Clay with Sand	
Soil Friction Angle (ϕ degrees):	27
Soil Cohesion (c, psf):	104.45
Soil Effective Unit Weight (γ', psf):	
Allowable length (ft)	

Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)
	Clay with Sand	19	5
	Sandy Clay Till	21	10
	Shale Bedrock	25	10
	Upper Fill	20	0

Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)
	Clay with Sand	19	5
	Sandy Clay Till	21	10
	Shale Bedrock	25	10
	Upper Fill	20	0



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Axial Forces

Pipe outside diameter	OD	12.5	inches
Pipe Coating Dependent Factor (f)	Rough Steel	0.8	
Depth of cover	DOC	6.56	ft
Depth to pipe centerline	H	7.08	
Soil cohesion	c	104.5	psf
Internal friction angle for soil	ϕ	27.0	degrees
Effective unit weight of soil	γ	135.0	lb/ft3
Coefficient of pressure at rest	K_o	0.546	
Adhesion factor	α	1.02	
Interface angle for pipe-soil	δ	21.6	degrees
Tan of interface angle	tanδ	0.396	
Axial soil force	Tu	1307.5	lbs/ft
		1.31	kips/ft

Coating dependent factor

Concrete	*1*
Coal Tar	*0.9*
Rough Steel	*0.8*
Smooth steel	*0.7*
Fusion Bonded Epoxy	*0.6*
Polyethylene	*0.6*

Lateral Forces

Pipe outside diameter	OD	12.5	inches
Depth of cover	DOC	6.56167979	ft
Depth to pipe centerline	H	7.08	
Effective unit weight of soil	γ	135	lb/ft3
Soil cohesion	c	104.45	psf
Internal friction angle for soil	ϕ	27	degrees
Horizontal bearing capacity factor for clay	N_{ch}	3.795	
Horizontal bearing capacity factor for sand	N_{qh}	3.872	
a		3.825	
b		0.997	
c		-0.090	
d		0.005	
e		0.000	
H/D		0.047	

Lateral soil force	Pu	4269.4	lbs/ft
		4.27	kips/ft

Lateral Bearing Capacity Factor of Soil

	ϕ (degrees)	a	b	c	d	e
Nch	0	6.752	0.065	-11.063	7.119	
Nqh	20	2.399	0.439	-0.03	1.06E-03	-1.75E-05
	25	3.332	0.839	-0.09	5.61E-03	-1.32E-04
	30	4.565	1.234	-0.089	4.28E-03	-9.16E-05
	35	6.816	2.019	-0.146	7.65E-03	-1.68E-04
	40	10.959	1.783	0.045	-5.43E-03	-1.15E-04
	45	17.658	3.309	0.048	-6.44E-03	-1.30E-04

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Vertical Forces

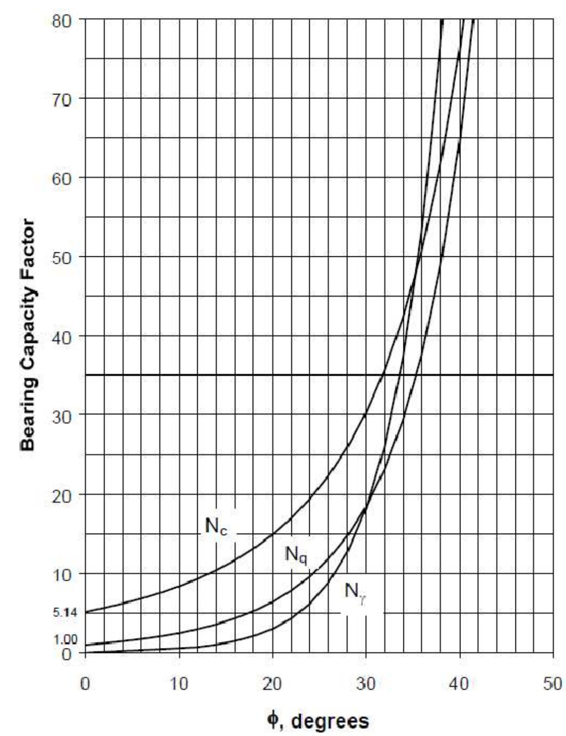
Pipe outside diameter	OD	12.5	inches
Depth of cover	DOC	6.56167979	ft
Depth to pipe centerline	H	7.08	
Effective unit weight of soil	$\underline{\gamma}$	135	lb/ft3
Total unit weight of soil	γ	135	
Soil cohesion	c	104.45	psf
Internal friction angle for soil	ϕ	27	degrees
Vertical bearing capacity factor	N_c	23.94	
Vertical bearing capacity factor	N_q	13.20	
Vertical bearing capacity factor	N_γ	10.59	

Vertical Bearing Soil Force	Q_d	16526.9	lbs/ft
		16.53	kips/ft

Vertical bearing capacity factor	N_{cv}	0.094	<10 ok
Vertical bearing capacity factor	N_{qv}	4.172244094	<Nq ok

Vertical Uplift Soil Force	Q_u	4165.74	lbs/ft
		4.17	kips/ft

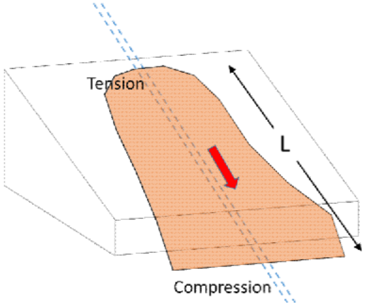
Bearing Capacity Factor of Soil



Longitudinal PGD Stress

Pipe outside diameter	OD	12.5	inches
Wall thickness of pipe	t	0.37519685	inches
Pipe Grade / SMYS	X-52	52000	5%
Modulus of elasticity	E	29,000,000	psi
Length of PGD zone/Length of pipe in slide	L	473.0012359	ft
Axial soil force	Tu	1307.46	lbs/ft
Elastic strain	ε_{el}	0.072%	
Plastic strain	ε_{pl}	0.000%	
Total strain	ε_{tot}	0.072%	
Bending Stress on pipe	σ_{axial}	20,986.5	psi PASS
Design Factor		0.54	
Pipe Internal Diameter	ID	11.7496063	in.
Maximum Operating Pressure	MOP	573	psi
Allowable Stress		28080	psi
Internal pressure stress		4772.49	psi
Remaining Stress Available		23307.51	psi
Allowable length of Longitudinal PGD		525.31	ft

Pipeline crossing permanent ground deformation zone in the direction of ground movement.



Pipe Grade	Yield stress (psi)	n	r
Grade B	35000	10	100
X-42	42000	15	32
X-52	52000	9	10
X-60	60000	10	12
X-70	70000	5.5	16.6
		9	10

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Transverse PGD Stress

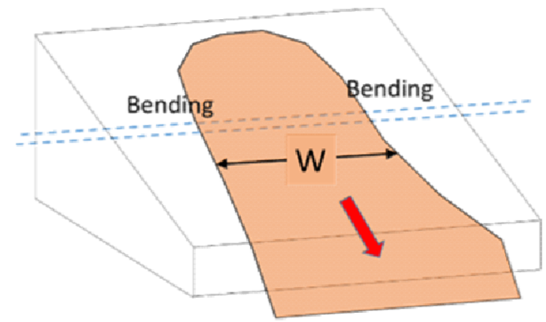
Pipe outside diameter	OD	12.50	inches
Wall thickness of pipe	t	0.37519685	inches
Pipe Grade	X-52	52000	
Modulus of elasticity	E	29,000,000	psi
Width of PGD zone/Length of pipe in slide	L	473.0012359	ft
Lateral soil force	Pu	4269.41	lbs/ft
Elastic strain	ε_{el}	71.536%	

Bending stress on pipe	σ_{axial}	**20,745,456.8**	psi	**FAIL**

Design Factor		0.54	
Pipe Internal Diameter	ID	11.7496063	in.
Maximum Operating Pressure	MOP	711	psi
Allowable Stress		28080	psi
Internal pressure stress		5921.89	psi
Remaining Stress Available		22158.11	psi

Allowable length of Longitudinal PGD		15.46	ft

Pipeline crossing permanent ground deformation zone transverse to the direction of ground movement.



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Attachment B

Screening Guidance, Evaluation Worksheets and Checklists

Attachment B-1

Supplemental Screening Guidance

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Supplemental Screening Guidance

Companion to the Bank Stability Assessment Manual
Water Crossing Program Technical User Guide Support Material

Revision 0 | January 2025

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Revision Record

Revision No.	Date Issued	Reviewed By	Description
0	1.2025	Svetlana Shafrova, EMTech	Developed supplemental screening guidance in support of bank stability assessment methodology for the Water Crossing Program.

Relevance

This supplemental screening guidance document is an attachment to the *Bank Stability Assessment Manual*, which is a companion to the Water Crossing Program Technical User Guide.

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Contents

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1 Introduction

This guidance provides instructions for performing bank stability desktop screening using examination of aerial imagery, alignment sheet profiles, and field photographs. The guidance is based on lessons learned from geotechnical Subject Matter Expert (SME) review of over a thousand bank stability desktop screenings of crossings located around the world.

Information and results of bank stability desktop screenings are documented in the Bank Stability Screening Excel Workbook, and SME reviews are documented in a separate Quality Assurance and Quality Control (QAQC) Workbook.

2 Assessment

This section describes the documentation of data sources in the Bank Stability Screening Excel Workbook and provides guidance for answering Bank Stability Screening Tool questions.

2.1 Quality of Data

Data used for bank stability desktop screening may come from publicly available sources, visual inspections, and/or surveys. Within the Bank Stability Screening Excel Workbook, select the applicable quality of data type:

- Publicly available data is chosen when there are no local aerials, pre-construction alignment sheets, post-construction surveys, or visual inspections.
- Visual inspection data is chosen when available from a field inspection (i.e., performed by a surveyor or EMPCo Water Crossing Engineer [WCE]). Photographs are reviewed for signs of instability and erosion using guidance from the field inspection sections of the *Bank Stability Assessment Manual* and the *Bank Stability Checklist Training for Water Crossing Engineers and Contractors* slide deck.
- Survey data is chosen when available from post-construction pipeline surveys at the crossing. These data allow precise calculation of slope ratio and height, setback distance, and depth of cover at the survey date; however, conditions at the time of screening may be different than the survey. Pro Surveys typically include a series of photographs similar to visual inspection data that should be studied for signs of instability.
- Survey data is also chosen when available from design (pre-construction) or as-built alignment sheets. As-built surveys are preferred since they show post-construction slopes of channel banks. Bank slopes, especially ditches, are often re-graded, mulched, and seeded during pipeline construction and may have a different configuration than the design profile.

Note that the number of questions in the Bank Stability Screening Tool vary based on the “available data” field; many questions may be grayed out when there are no visual inspections. These unneeded rows can be hidden to provide space for pertinent questions to fit vertically on the page. All questions in the screening form become available for input when “visual inspection data” or “survey data” are selected.

2.2 Documentation

Information recorded in the Bank Stability Screening Excel Workbook should be documented consistent with universally understood terms to expedite subsequent reviews by the WCE and SME. If the project is in metric units,

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the screener should keep all measurements in meters rather than converting them to feet. Google Street View should be used whenever possible to view conditions at the crossing such as slopes and vegetation along the waterway, even when the Street View marker is along a bridge several hundred feet from the crossing. Titles and dates for all materials referenced for the screening should be recorded in the "Notes" column, including surveys, alignment sheet numbers, report titles, and inspection photos. The source and date of publicly available imagery used to make interpretation such as Google Earth Aerial Imagery (GEAI) and Google Street View images should also be noted. It is understood that Microsoft Bing Maps Photos do not have dates. Row 8 of the Bank Stability Screening Excel Workbook should be used to document parallel pipelines, alignment sheet numbers, depth of cover, setback estimates, and horizontal directional drill.

Record general observations and notes about the crossing; examples are listed below.

- Fallen trees, debris, etc. within channel;
- Culverts, armoring, or bridges (including foot bridges) within 10 channel widths;
- Dry or intermittent flows in channel based on aerial images;
- Data sources and dates (e.g., "based on GEAI 3/2022");
- Channel description, i.e. narrow and shallow stream, no visible channel, channel barely visible, major river, minor stream, ditch, or roadside ditch;
- Disturbance due to pipeline construction (when image is during pipeline construction and crane mats are present);
- State no clear image when images are dark or obstructed by clouds or have poor resolution;
- Minor erosion, active erosion, significant erosion;
- Riverine threat or no bank stability concerns, erosion issue.

2.3 Screening Questions

Performing bank stability desktop screening requires a thorough understanding of the screening questions included in the Bank Stability Screening Tool in order to provide the best estimates based on available data. If a question cannot be answered directly from available data, choose the most conservative response and note "conservative assumption". This section explains what information is needed to answer the bank stability screening questions.

Question No. 1: Slope Ratio and Height

Slope heights/depths are critical to the evaluation and should be noted when possible. A professional survey is the most accurate representation of the crossing and should be used if available. Alignment sheets may be used if their vertical resolution captures the crossing; this can be done by using the measure function in a PDF editor and comparing it to the drawing's vertical and horizontal scales. The "All Assessments" Inventory Verification Spreadsheet (if provided) has estimated crossing widths if needed.

Acceptable descriptions of slope ratio and height in the "Notes" column are listed below.

- Show calculation of slope ratio, i.e., 27/9=3.0;
- Indicate source for basis of numbers, i.e., 2010 as-built, 2010 professional survey, etc.;
- Slopes x:x or flatter (based on steepest slope of profile);
- Very steep banks or near vertical banks;
- Conservative assumption.

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Questions No. 2 and No. 3: Soil Type and Strength

The soil type and strength are typically unknown and conservative assumptions of CH (i.e., fat clay) and soft are often used and noted as a conservative assumption. Soft fat clay and loose saturated sand are the soil compositions most likely to lead to slope instability. Soil properties may be based on a pre-construction geotechnical report such as for horizontal direction drilling and/or borehole data along the planned route, publicly available soil data from a Geographic Information System or published geology maps, or visually interpreted from field photos. When geotechnical reports are available, the geotechnical SME may review them and provide expected soil types. The best-case scenario is when the SME can provide soil types referenced to pipeline stationing, i.e., soil types by station limits along the alignment.

Question No. 4: Inundation

The WCE typically determines whether the crossing can become inundated based on information from flood maps and stream gages, but this information is likely unavailable at the time of the bank stability screening. In lieu of WCE guidance, historical images may be used to determine whether the waterway becomes bank full. If the screener is unsure, they should choose “yes” and note it as a conservative assumption.

Question No. 5: Vegetation

Changes in vegetation over time should be noted. During cool temperature seasons, vegetation typically undergoes noticeable changes in appearance as a response to the changing environmental conditions. For instance, grassy vegetation may turn brown and deciduous trees lose their leaves entirely. Seasonal changes should not be confused with erosion or instability. Acceptable descriptions of vegetation include woody vegetation, tree lined banks, and loss of vegetation at crossing or upstream/downstream of crossing.

Question No. 8: Previous Landslide Activity

Landslides can be identified on aerial photography by carefully examining visual indicators and comparing them to the surrounding landscape. First, look for irregular landforms such as steep slopes or scarps that appear different from the surrounding terrain and may indicate the movement and displacement of soil or rock. Look for fresh or exposed earth material that contrasts with the surrounding vegetation or soil cover, as landslides often strip away the organic top layers. Pay attention to areas with displaced or disrupted vegetation, such as piles of grass near the toe, uprooted trees, or bare patches. Additionally, look for signs of debris flow, such as the presence of bulging deposits or fan-shaped patterns downstream from steep slopes. Acceptable descriptions of landslide activity in the “Notes” column are listed below.

- No visible evidence of instability;
- Sloughing, minor sloughing, landslide, catastrophic landslide;
- Banks show disturbance (when uncertain if related to instability).

Question No. 7: Land Drainage

A description of the terrain is useful in the “Notes” column, i.e., flat terrain, rolling hills, hilly terrain, or mountainous terrain. ArcGIS World Topo Map may be used during the screening to determine drainage and terrain.

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Question No. 10: Undercutting

It is important to specify *undercutting* versus *trees obscuring right-of-way (ROW)*. Note which applies to the crossing. Typically, undercutting is only visible in field photos or Google Earth Street View, although it may be interpreted from aerial images showing fallen or leaning trees near the waterline.

Bank Screening Outcome

Interpreted results of the bank stability screening (i.e., the screener's professional opinion) should be provided as the "Bank Screening Outcome". The screening outcome can be different from the Bank Stability Scorecard outcome based on interpretation of visual evidence. The geotechnical SME will also provide their "SME Outcome" as the final answer/result from the bank stability screening. The screener's observations and opinion weigh into the SME evaluation and helps the SME be conservative with the evaluations. Ultimately, the screening process aims to result in a prioritized list of crossings that require collection of field data and photographs to fill data gaps and allow a more complete assessment.

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Attachment B-2

Desktop Screening Checklist

Pipeline System						
Crossing Name						
Crossing ID						
Bank Stability Screening Status	Not Started		QAQC Needed		QAQC Complete	
Last Quarter Completed						
Coordinates						
What quality of data is available?	Publicly Available		Visual Inspection		Survey	
Notes						
	Water Crossing Measurement	Notes	Water Crossing Measurement	Notes	Water Crossing Measurement	Notes
1 Slope Ratio (horizontal to vertical ratio). If unknown, put NA. Use worst bank (slope AND height) if you have a survey.						
Height (in feet). If unknown, put NA. Use same bank as question 1.						
2 Bank slope soil type: a) Fat clay; b) lean clay; c) sand.						
3 Bank slope soil strength: a) Stiff, strong or very dense; b) soft, weak or loose						
Can the bank ever get fully inundated?						
5 Vegetation cover on slope face: a) Well vegetated with trees; b) light vegetation (mostly grass); or c) no vegetation/recent changes in vegetation						
6 Seepage from slope face: Is there evidence of groundwater seepage exiting from the slope of the banks above the typical low water line? (This is sometimes						
7 Land drainage: a) Flat; b) minor drainage over slope; or c) drainage over slope with erosion gullies						
8 Previous landslide activity: Is evidence of recent or historical bank sloughing visible (large parts of bank have slid downward into the channel i.e. terraces)? Within 10 channel widths upstream/downstream of the crossings.						
9 Erosion: Is active erosion visible at the crossing (or upstream and downstream) or upstream culvert within 2 channel widths?						
10 Undercutting: If visual inspection available, are trees on the bank with exposed and overhanging roots? If visual inspection not available, do trees obscure the ROW or hang over the bank upstream?						
11 Are any soil cracks on the slopes or above the banks? Note if parallel or perpendicular to stream and note the amount of displacement (width).						
12 Are depressions or larger sinkholes within or near ROW?						
13 Are animal burrows present on the slope face?						
Bank Stability Screening Score	Pending - No		Pending - No		Pending - No	
Bank Stability Screening Outcome	No		No		No	

Geotechnical Engineer Review Needed?	No	No	No
Geotechnical Engineer Review Result			
Geotechnical Engineer Review Notes			
QA/QC WCE Name			
QA/QC Quarter			

Attachment B-3

Basis of Checklist

ExxonMobil Global Pipeline Integrity Rev 5 - 12/30/2024

Water Crossing Program - Bank Stability Inspection Checklist

Water Crossing Name and ID		**Date Sent to Water Crossing Program**	
Pipeline System and TLC		**Date Inspection Completed**	
Pipeline Segment		**Date of Previous Inspection (if applicable)**	
Latitude			
Longitude			

Left Bank

Horizontal Directional Drill (HDD) Setback Question:		**Yes**	**No**	**N/A**
1	If the pipeline at the water crossing was installed via HDD, is the setback known to be greater than 1/4 of channel width. If yes, no further inspection is required at this time.			
Floodplain and Channel Migration Questions:		**Yes**	**No**	**N/A**
1	Is a washout (a field runoff ditch or stream) near (within 150 feet upstream and downstream) or running over the top of the EMPCo ROW that drains to the main channel?			
2	Have trees along the banks fallen or are currently falling into the channel? Are tilted or curved trees growing along the slope or at the toe of the slope?			
3	Is evidence visible that the channel high bank has eroded or migrated significantly over time?			
4	Are areas with soft or disturbed ground with poor drainage and ponded water present?			
Bank Stability Questions:		**Yes**	**No**	
1	Slope Ratio and Height (first box horizontal to vertical ratio, second box height in feet)			
2	Bank slope soil type: a) Fat clay; b) lean clay; c) silt, d) sand; e) other (describe)			
3	Bank slope soil strength: a) Stiff, strong or very dense; b) soft, weak or loose			
4	Vegetation cover on slope face: a) Well vegetated with trees; b) light vegetation (mostly grass); or c) no vegetation			
5	Seepage from slope face: Is there evidence of groundwater seepage exiting from the slope of the banks above the typical low water line? (This is sometimes indicated by patches of different vegetation)			
6	Land drainage: a) Flat; b) minor drainage over slope; or c) drainage over slope with erosion gullies			
7	Previous landslide activity: Is evidence of recent or historical bank sloughing visible (large parts of bank have slid downward into the channel i.e. terraces)?			
8	Undercutting: Are trees on the bank with exposed and overhanging roots?			
9	Are any soil cracks on the slopes or above the banks? Note if parallel or perpendicular to stream and note the amount of displacement (width).			
10	Are depressions or larger sinkholes within or near ROW?			
11	Are animal burrows present on the slope face?			
External Factors Questions:		**Yes**	**No**	**N/A**
1	Has the area experienced long-term drought?			
2	Has the area experienced a recent (past 3 months) flood event?			
3	Is debris buildup accumulating in the channel (especially near the toe of the bank)? Upstream or downstream?			
4	Are other pipelines upstream of the EMPCo lines within the channel?			
4a	If yes, are the upstream pipelines exposed (in air or water)?			
4b	If yes, is armoring (concrete, matting, rip-rap, palisades) known or visible?			
Monitoring Options:		**Yes**	**No**	**N/A**
1	Can pictures be taken to show upstream, downstream and pipeline crossing location? (If so, then please take pictures and include as part of this response.)			
2	Does Aerial Patrol take photos of the water crossing every 2 weeks? Or after regional flooding events?			
3	Could installing numbered monitoring stakes at 5 foot intervals at the water crossing be an option?			

Attachment B-4

Field App Checklist (Survey123)

Denise

Bank Stability Inspection

General

Water Crossing Name

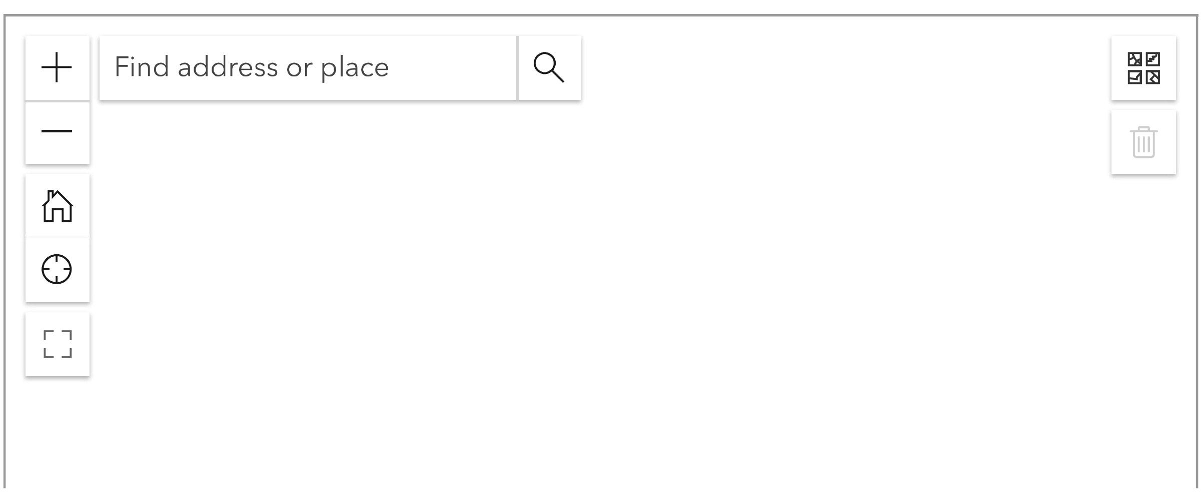
Water Crossing ID

Operations Area

-Please Select-

Pipeline TLC

Set start location



San Bernardino County, Maxar

Powered by Esri

Lat: °

Lon: °

Date Inspection Completed

m/d/yyyy

Has the area experienced long-term drought?

- Yes
- No
- Unknown

Notes

Has the area experienced a recent (past 3 months) flood event?

If yes, note approximate date.

- Yes
- No
- Unknown

Notes

Is debris buildup accumulating in the channel (especially near the toe of the bank)?

If yes, note where, indicate type of debris buildup and take a picture. Specify frequency of debris removal, if known.

- Yes
- No
- Unknown

Notes

Debris Image

Select image file

Add description of debris image as needed

Are other pipelines upstream of the EMPCo lines within the channel?

Yes

No

Unknown

Notes

If yes, are the upstream pipelines exposed (in air or water)?

Yes

No

Unknown

Notes

Is armoring (concrete, rip-rap, palisades, grout bags, bulkheads, etc.) known or visible at or upstream of the crossing?

If yes, note type of armoring and location, and take pictures.

Yes

No

Unknown

Notes

Armoring Image

Select image file

Add description of armoring image as needed

Add photo upstream of, downstream of, and at the water crossing. If multiple pipelines are shown in the pictures below, add an arrow or point to the pipeline of interest. Add comment indicating which bank you were standing on when the photo was taken.

Upstream Image

Select image file

Add description of upstream image as needed

Downstream Image

Select image file

Add description of downstream image as needed

Water Crossing Image

Select image file

Add description of water crossing image as needed

Checklist for Left Bank

Floodplain and Channel Migration Questions:

Is a washout (a field runoff ditch or stream) near (within 150 feet upstream and downstream) or running over the top of the EMPCo ROW that drains to the main channel?

If yes, note where washout is seen.

- Yes
- No

Notes

Have trees along the bank fallen or are currently falling into the channel?

If yes, note where trees are observed.

- Yes
- No

Notes

Are tilted or curved trees growing along the slope or at the toe of the slope?

If yes, note where trees are observed.

- Yes
- No

Notes

Is evidence visible that the channel bank has eroded or migrated significantly over time?

If yes, note where.

- Yes

Notes

Are areas with soft or disturbed ground with poor drainage and ponded water present?

If yes, note where.

Yes

No

Notes

Bank Stability Questions:

Slope Ratio (horizontal to vertical ratio)

Height (in feet)

Bank slope soil type:

Lean Clay

Silt

Sand

Other

If other, describe:

Bank slope soil strength:

Stiff, strong or vey dense

medium stiff or dense

soft, weak, or loose

Notes

Vegetation cover on slope face:

Well vegetated with trees

○ Light vegetation (mostly grass)

○ No vegetation

Notes

Seepage from slope face: Is there evidence of groundwater seepage exiting from the slope of the banks above the typical low water line? (This is sometimes indicated by patches of different vegetation)

○ Yes

○ No

Notes

Land drainage:

○ Flat

○ Minor drainage over slope

○ Drainage over slope with erosion gullies

Notes

Previous landslide activity: Is there evidence of recent or historical bank sloughing visible (large parts of banks have slid downward into the channel i.e. terraces)?

If yes, note where.

- Yes
- No

Notes

Erosion: Is active erosion visible at the crossing (or upstream and downstream)?

If yes, note where.

- Yes
- No

Notes

Undercutting: Are trees on the bank with exposed and overhanging roots?

Yes

No

Notes

Are any soil cracks present on the slopes or above the banks?

Note if parallel or perpendicular to stream and note the amount of displacement (width).

Yes

No

Notes

Are depressions or larger sinkholes within or near ROW?

If yes, note where and indicate size.

Yes

No

Notes

Are animal burrows present on the slope face?

If yes, note where and indicate size.

- Yes
- No

Notes

Left Bank Images

Add photos of bank and observations documented above. If multiple pipelines are shown in the below pictures, add an arrow or point to the pipeline of interest

Left Bank Ribbon Test

Select image file

Add description of image as needed

Left Bank Thread Test

Select image file

Add description of image as needed

Left Bank Thumb Indentation Test

Select image file

Add description of image as needed

Any additional image

Select image file

Add description of image as needed

Any additional image

Select image file

Add description of image as needed

Any additional image

Denise

Add description of image as needed

Any additional image

Select image file

Add description of image as needed

Any additional image

Select image file

Add description of image as needed

Checklist for Right Bank

Floodplain and Channel Migration Questions:

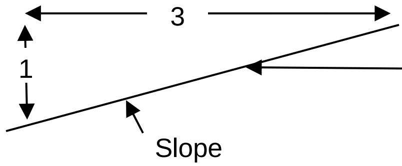
Bank Stability Questions:

Right Bank Images

Attachment B-5

Slope Conversion Tables

Slope Conversion Tables



Slope Ratio: 3:1 or 3 to 1
Percent Slope: 33%
Degree Slope: 18.4º
Inches per Foot: 4

	Horizontal to Vertical Slope Ratio (__ to 1)																								
	1/4	**1/2**	**3/4**	**1**	**1-1/4**	**1-1/2**	**1-3/4**	**2**	**2-1/2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
Percent Slope	400	200	133	100	80	67	57	50	44	33	25	20	16.7	14.3	12.5	11.1	10.0	9.1	8.3	7.7	7.1	6.7	6.3	5.9	5.6
Degrees Slope	76.0	63.4	53.1	45.0	38.7	33.7	29.7	26.6	24.0	18.4	14.0	11.3	9.5	8.1	7.1	6.3	5.7	5.2	4.8	4.4	4.1	3.8	3.6	3.4	3.2
Inches per Foot	48	24	16	12	9.6	8	6.9	6	5.3	4	3	2.4	2.0	1.7	1.5	1.3	1.2	1.1	1.0	0.92	0.86	0.80	0.75	0.71	0.67

	Percent Slope																								
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**
Horizontal/Vertical	100	50	33.3	25	20	16.7	14.3	12.5	11.1	10	9.1	8.3	7.7	7.1	6.7	6.3	5.9	5.6	5.3	5.0	4.8	4.5	4.3	4.2	4.0
Degrees Slope	0.6	1.1	1.7	2.3	2.9	3.4	4.0	4.6	5.1	5.7	6.3	6.8	7.4	8.0	8.5	9.1	9.6	10.2	10.8	11.3	11.9	12.4	13.0	13.5	14.0
Inches per Foot	0.1	0.2	0.4	0.5	0.6	0.7	0.8	1.0	1.1	1.2	1.3	1.4	1.6	1.7	1.8	1.9	2.0	2.2	2.3	2.4	2.5	2.6	2.8	2.9	3.0

	Degrees Slope																								
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**
Percent Slope	1.7	3.5	5.2	7.0	8.7	10.5	12.3	14.1	15.8	17.6	19.4	21	23	25	27	29	31	32	34	36	38	40	42	45	47
Horizontal/Vertical	57	29	19	14	11	9.5	8.1	7.1	6.3	5.7	5.1	4.7	4.3	4.0	3.7	3.5	3.3	3.1	2.9	2.7	2.6	2.5	2.4	2.2	2.1
Inches per Foot	0.2	0.4	0.6	0.8	1.0	1.3	1.5	1.7	1.9	2.1	2.3	2.6	2.8	3.0	3.2	3.4	3.7	3.9	4.1	4.4	4.6	4.8	5.1	5.3	5.6

	Inches per Foot																								
	1/8	**1/4**	**3/8**	**1/2**	**5/8**	**3/4**	**7/8**	**1**	**1-1/8**	**1-1/4**	**1-3/8**	**1-1/2**	**1-5/8**	**1-3/4**	**1-7/8**	**2**	**2-1/8**	**2-1/4**	**2-3/8**	**2-1/2**	**2-5/8**	**2-3/4**	**2-7/8**	**3**	**3-1/8**
Percent Slope	1.0	2.1	3.1	4.2	5.2	6.3	7.3	8.3	9.4	10.4	11.5	12.5	13.5	14.6	15.6	16.7	17.7	18.8	19.8	20.8	21.9	22.9	24	25	26
Degrees Slope	0.6	1.2	1.8	2.4	3.0	3.6	4.2	4.8	5.4	5.9	6.5	7.1	7.7	8.3	8.9	9.5	10.0	10.6	11.2	11.8	12.3	12.9	13.5	14.0	14.6
Horizontal/Vertical	96	48	32	24	19	16	14	12	10.7	9.6	8.7	8.0	7.4	6.9	6.4	6.0	5.6	5.3	5.1	4.8	4.6	4.4	4.2	4.0	3.8

Attachment B-6

Example Bank Stability Scorecard

Bank Stability Checklist Scoring Sheeting *Revision: 6* *Date: 2024.12.30*

These sheet is to be used for river bank stability screening purposes. When existing inspection data is available, a WCE can fill out this to perform general screening. This may not require a full Bank Stability Inspection Checklist be filled out, but it is recommended that survey or other means of verifying bank height and slope be available prior to completion.

Steps:
1. Complete the 12 bank slope stability questions based on available data
2. Record any sensitivity notes needed in the blue boxes to the right
3. Approximate a failure plane on the bank based on the FOS tool examples
4. Include a screen grab of the survey bank and the FOS run used.
5. Note the final FOS color code for the assessment. For Yellow or Red, an Geotechnical Engineer review may be needed.
6. Evaluate proper setback based on approximated failure plane based on FOS tool.
7. Repeat above process on other bank.

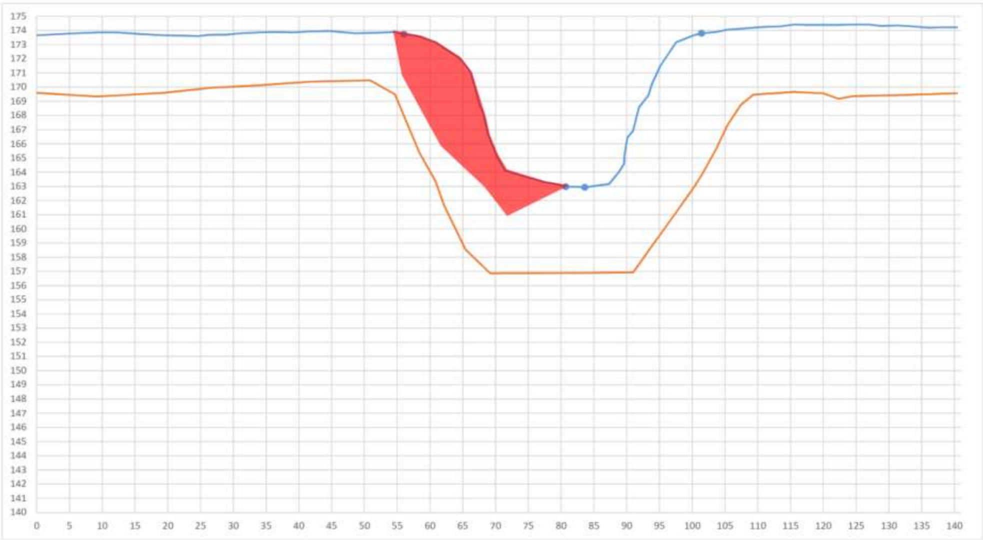
Change Log		
5	Formatting changes, addition of instructions, added change log	2019.10.08
6	Hid Screening Test Tab. Team should perform BS Screening using the separate screening tool as discussed in team BS Workshop on 3/5/21	3/11/2021
7	Updated the formula in cell N13 on Right and Left Bank Scoring tab such that equation for FOS < 1.3 (yellow) for Stiff Fat Clay matches that shown in graph in 2017 Stability Hazard Assessment report as verified by Arcadis in 2022. Equation updated from Slope Height > 4.7*e^(0.71*Slope) to Slope Height > 2.23*e^(1.06*slope).	3/17/2022
8	Eliminated question on erosion activity since there is always erosion and it was redundant with questions 6 and 8.	12/30/2024

ExxonMobil Global Pipeline Integrity Revision 6

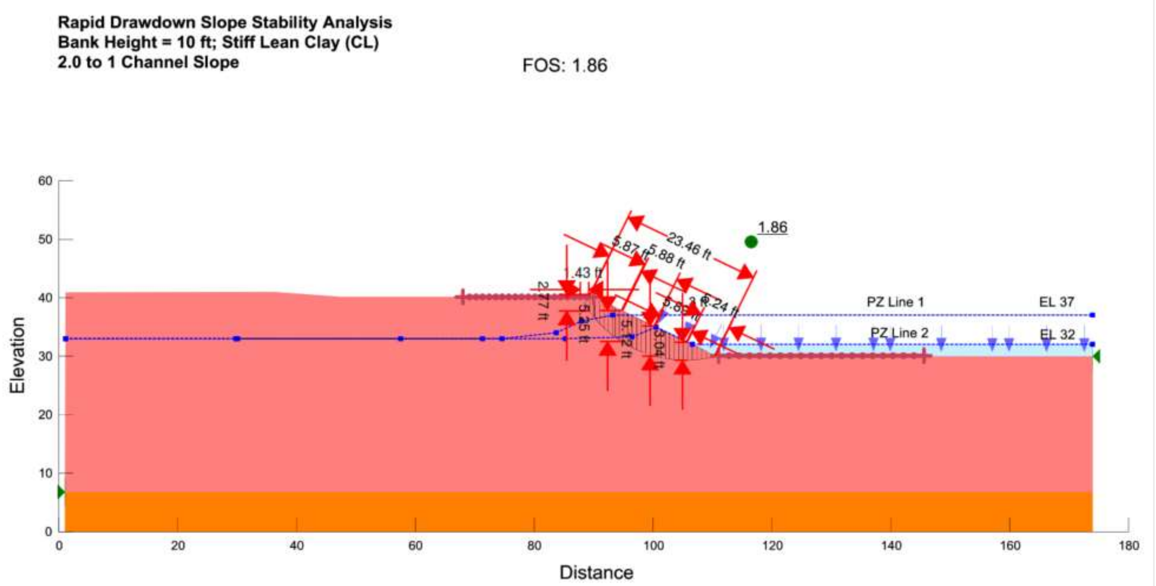
Water Crossing Program Bank Stability Site Inspection Question/Checklist

Bank Stability Questions:		Yes	No	Rationale
1	Slope Ratio and Height (first box horizontal to vertical ratio, second box height in feet)	2.3	10.8	GREEN
2	Bank slope soil type: a) Fat clay; b) lean clay; c) silt, d) sand	b		
3	Bank slope soil strength: a) Stiff, strong or very dense; b) soft, weak or loose	a		
	FOR WCE - Can the bank ever get fully inundated	x		
4	Vegetation cover on slope face: a) Well vegetated with trees; b) light vegetation (mostly grass); or c) no vegetation	b		GREEN
5	Seepage from slope face: Is there evidence of groundwater seepage exiting from the slope of the banks above the typical low water line? (This is sometimes indicated by patches of different vegetation)		x	GREEN
6	Land drainage: a) Flat; b) minor drainage over slope; or c) drainage over slope with erosion gullies	b		GREEN
7	Previous landslide activity: Is evidence of recent or historical bank sloughing visible (large parts of bank have slid downward into the channel i.e. terraces)?	x		RED
8	Undercutting: Are trees on the bank with exposed and overhanging roots?	x		RED
9	Are any soil cracks on the slopes or above the banks? Note if parallel or perpendicular to stream and note the amount of displacement (width).		x	GREEN
10	Are depressions or larger sinkholes within or near ROW?		x	GREEN
11	Are animal burrows present on the slope face?		x	GREEN
	SCORE			**RED**

Survey Mark Up Screenshot



FOS Tool Screenshot



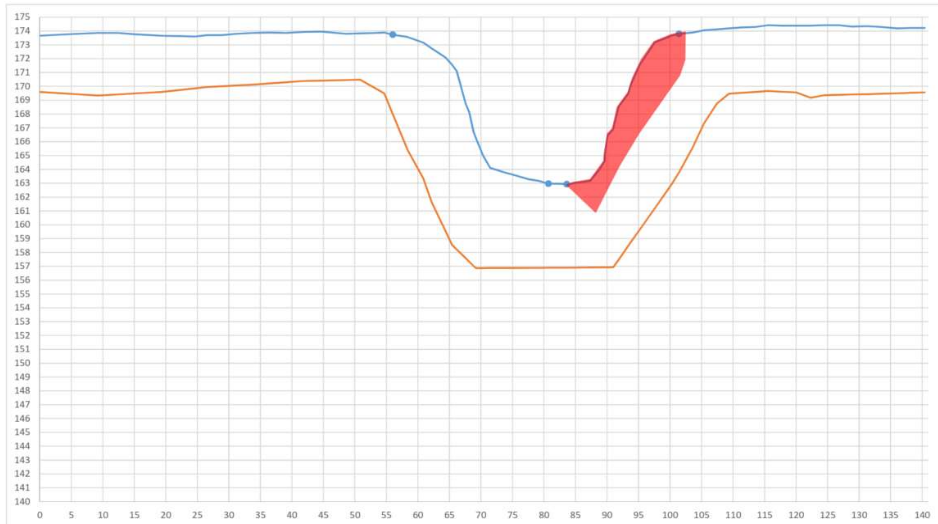
ExxonMobil Global Pipeline Integrity

Water Crossing Program Bank Stability Site Inspection Question/Checklist

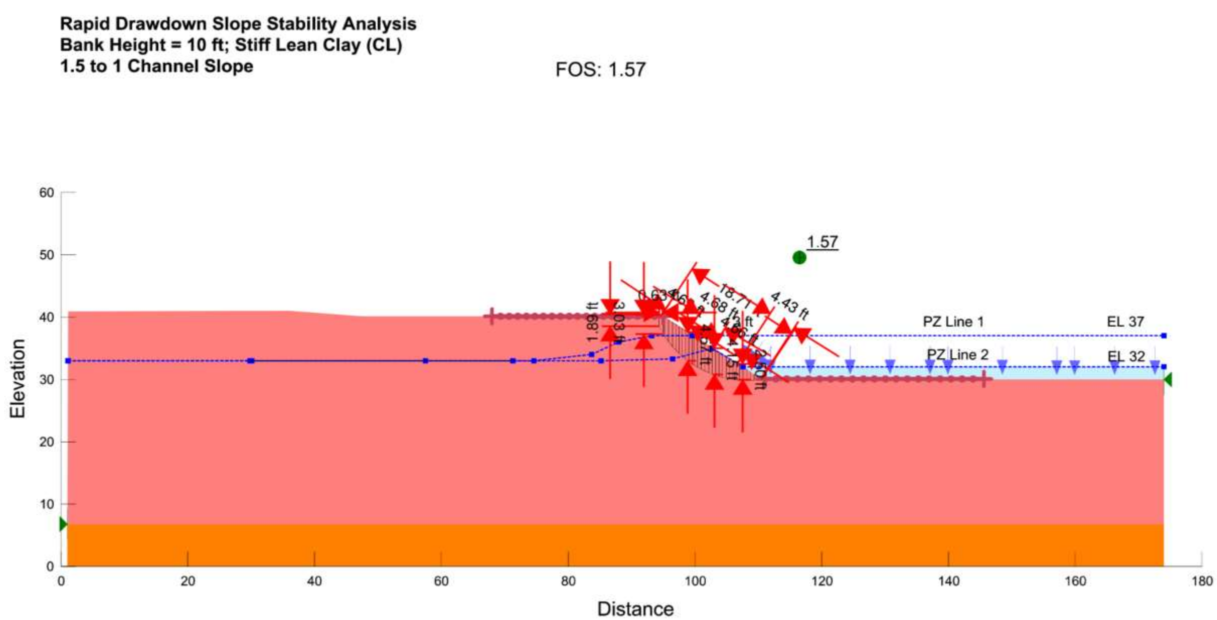
Revision 6

Bank Stability Questions:		**Yes**	**No**	**Rationale**
1	Slope Ratio and Height (first box horizontal to vertical ratio, second box height in feet)	1.6	10.9	GREEN
2	Bank slope soil type: a) Fat clay; b) lean clay; c) silt, d) sand	b		
3	Bank slope soil strength: a) Stiff, strong or very dense; b) soft, weak or loose	a		
	FOR WCE - Can the bank ever get fully inundated	x		
4	Vegetation cover on slope face: a) Well vegetated with trees; b) light vegetation (mostly grass); or c) no vegetation	b		GREEN
5	Seepage from slope face: Is there evidence of groundwater seepage exiting from the slope of the banks above the typical low water line? (This is sometimes indicated by patches of different vegetation)		x	GREEN
6	Land drainage: a) Flat; b) minor drainage over slope; or c) drainage over slope with erosion gullies	b		GREEN
7	Previous landslide activity: Is evidence of recent or historical bank sloughing visible (large parts of bank have slid downward into the channel i.e. terraces)?	x		RED
8	Undercutting: Are trees on the bank with exposed and overhanging roots?	x		RED
9	Are any soil cracks on the slopes or above the banks? Note if parallel or perpendicular to stream and note the amount of displacement (width).		x	GREEN
10	Are depressions or larger sinkholes within or near ROW?		x	GREEN
11	Are animal burrows present on the slope face?		x	GREEN
SCORE				**RED**

Survey Mark Up Screenshot



FOS Tool Screenshot



Attachment B-7

Slope Stability Hazard Matrix

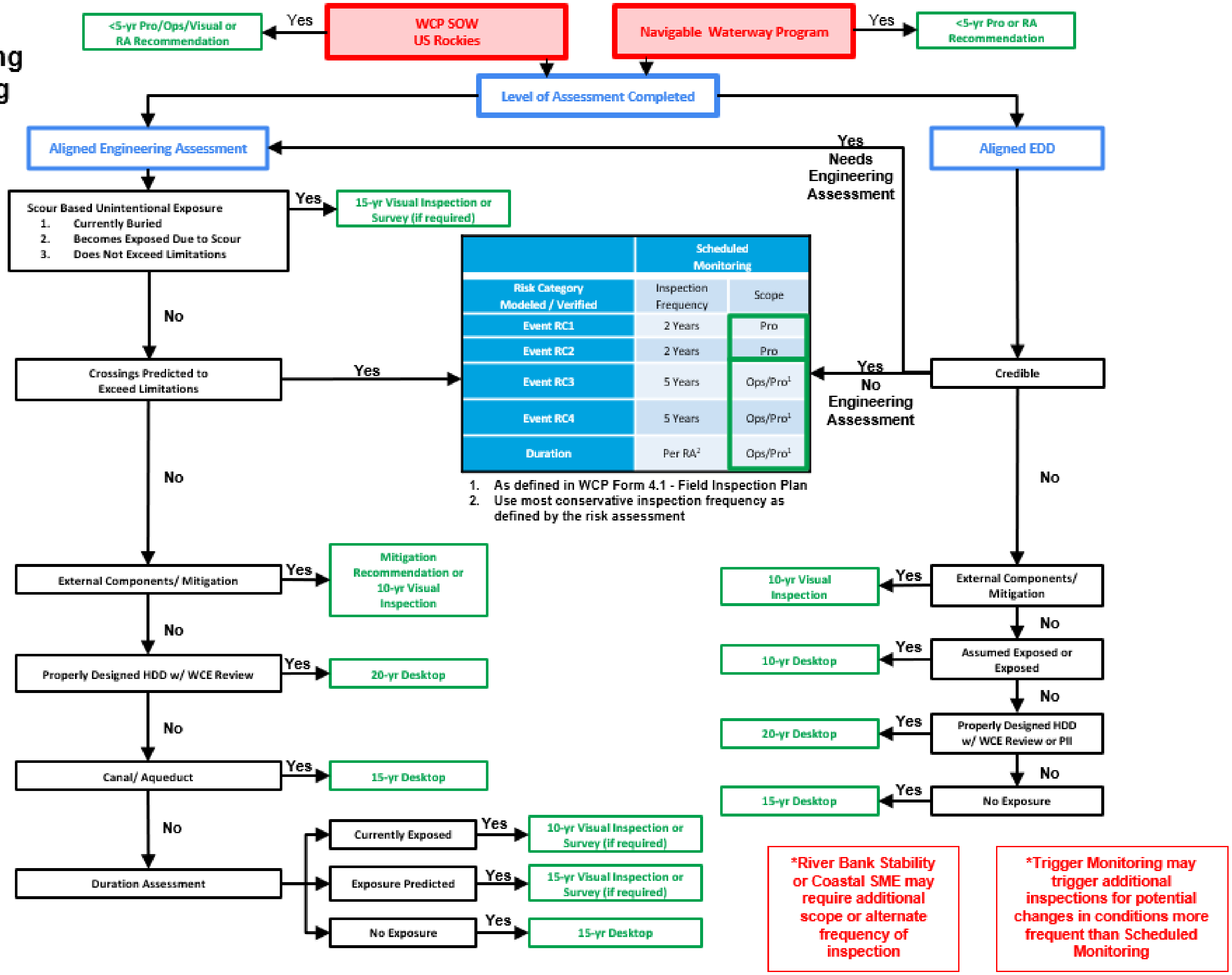
<table>
<tr><th colspan="6">Slope Stability Hazard Matrix for Pipeline Water Crossings</th></tr>
<tr><td colspan="6">The Slope Stability Hazard Matrix uses the score from Bank Stability Scorecard (i.e., most conservative color category from the Bank Stability Inspection Checklist scoring spreadsheet/site observations and slope stability FOS chart results). The color category represents the likelihood of slope failure. The matrix also uses a pipeline vulnerability input based on calculation of sufficient pipeline setback distance and depth of cover. The output of the matrix is an action which guides the WCEs through the process of assessing bank stability at pipeline water crossings. Definitions of Slope Failure likelihood from ExxonMobil Risk Matrix GMOP 2.1(B) - Attachment 1 were used.</td></tr>
<tr><th colspan="3">Slope Vulnerability</th><th colspan="3">Pipeline Vulnerability</th></tr>
<tr><th rowspan="2">Color Category</th><th rowspan="2">Slope Stability</th><th rowspan="2">Slope Failure</th><td>Sufficient setback (Pipeline >5 ft from Failure Planes*)</td><td>Unknown setback (Pipeline location unknown)</td><td>Insufficient setback (Pipeline within 5 ft of Failure Planes or Progressive Sloughing*)</td></tr>
<tr><td>Negligible</td><td>Marginal</td><td>Serious</td></tr>
<tr><td>Red</td><td>Very Low (Unstable)</td><td>Very Likely</td><td>Action 5</td><td>Action 1</td><td>Action 1</td></tr>
<tr><td>Yellow</td><td>Medium (Conditionally Stable)</td><td>Somewhat Likely</td><td>Action 5</td><td>Action 3</td><td>Action 2</td></tr>
<tr><td>Light Green</td><td>High (Likely Stable)</td><td>Unlikely</td><td>Action 5</td><td>Action 3</td><td>Action 4</td></tr>
<tr><td>Green</td><td>Very High (Stable)</td><td>Very Unlikely</td><td>Action 6</td><td>Action 6</td><td>Action 6</td></tr>
<tr><td colspan="6">*If Slope/W has not been run: “Failure Planes” is defined as critical failure plane pre-drawn in 2024 Guidance on Slope Failure Mechanisms and Stability Hazard Assessment report. If Slope/W has been run: “Failure Planes” is defined as those with FOS up to 1.5 for steady state and rapid drawdown loading.</td></tr>
<tr><th>Action #</th><th colspan="5">WCE Actions Based on Assessment</th></tr>
<tr><td>1</td><td colspan="5">Immediately engage Third Party SME to review inspection documents and professional survey, and schedule Third Party SME site visit. Notify Operations of recommended next steps, including obtaining professional survey if one is not available, following site visit. Third Party SME will run preliminary Slope/W analysis based on conservative soil assumptions and advise on need for soil borings, refined Third Party SME Slope/W assessment, and interim trigger monitoring or HWAP. Assess the structural condition/capacity of the pipe vs. predicted strain demand (run Soil Springs). Assess for bank stability threat per Third Party SME guidance, request review by ExxonMobil SME, and risk assess as needed. Based on risk assessment results, consider operational controls including HWAP and engineering controls or pipe reroute as needed. Assign scheduled monitoring frequency and trigger monitoring per Third Party/ExxonMobil SME input.</td></tr>
<tr><td>2</td><td colspan="5">Engage Third Party SME to review WCE inspection documents and professional survey and confirm that Third Party SME site visit is needed. Third Party SME will run preliminary Slope/W analysis based on conservative soil assumptions and advise on need for soil borings, refined Third Party SME Slope/W assessment, and interim trigger monitoring or HWAP. Assess the structural condition/capacity of the pipe vs. predicted strain demand (run Soil Springs). Assess for bank stability threat per Third Party SME guidance, request review by ExxonMobil SME, and risk assess as needed. Based on risk assessment results, consider operational controls including HWAP and engineering controls as needed. Assign scheduled monitoring frequency and trigger monitoring per Third Party/ExxonMobil SME input.</td></tr>
</table>

<table>
<tr><td>3</td><td>Request professional survey and consider WCE site visit as needed to finalize Bank Stability Inspection Checklist inputs. Assign trigger monitoring in interim as needed. Update score card based on site visit. Third Party SME shall run preliminary Slope/W analysis based on conservative soil assumptions to determine whether the pipeline is located within failure planes with FOS up to 1.5 for RDD loading or Steady State loading condition. Re-plot crossing in the Slope Stability Hazard Matrix based on updated pipeline vulnerability and evaluate the need for soil boring to eliminate conservatism from Slope/W analysis as needed.</td></tr>
<tr><td>4</td><td>If insufficient setback was determined based on overlay with pre-populated critical failure plane from the 2024 Guidance on Slope Failure Mechanisms and Stability Hazard Assessment report, then:
Third Party SME shall complete preliminary Slope/W analysis based on conservative soil assumptions to determine whether the pipeline is still located within failure planes with FOS <1.5 for RDD or Steady State condition. Re-plot crossing in the Slope Stability Hazard Matrix based on updated pipeline vulnerability and evaluate the need for soil boring to eliminate conservatism from Slope/W analysis as needed.
If insufficient setback was determined based on Slope/W analysis:
Consult with ExxonMobil geotechnical SME to assess the structural condition/capacity of the pipe vs. predicted soil loading (run Soil Spring) and risk assess crossings that are predicted to exceed pipeline limitations. Consult with ExxonMobil geotechnical SME when risk assessing and provide SME with Slope/W analysis and Soil Spring results to aid in determination of probability that soil loading will exceed pipeline limitations and result in loss of containment.
Assign scheduled monitoring and trigger monitoring per Third Party SME input.</td></tr>
<tr><td>5</td><td>If sufficient setback was determined based on survey overlay with pre-populated critical failure plane from the 2024 Guidance on Slope Failure Mechanisms and Stability Hazard Assessment report, then:
Third Party SME shall run preliminary Slope/W analysis based on conservative soil assumptions to determine whether the pipeline is located within failure planes with FOS up to 1.5 for RDD or Steady State loading condition. Re-plot crossing in the Slope Stability Hazard Matrix based on updated pipeline vulnerability and evaluate the need for soil boring to eliminate conservatism from Slope/W analysis as needed.
If sufficient setback was determined based on Slope/W analysis:
Assign scheduled monitoring and trigger monitoring per Third Party SME input.
For crossings with red/unstable or yellow/conditionally stable bank score, review recommendations with ExxonMobil SME and discuss whether Scenario Based Risk Assessment should be performed to capture potential threats associated with future progressive bank failure.</td></tr>
<tr><td>6</td><td>Assign scheduled monitoring and trigger monitoring per WCP guidelines.</td></tr>
<tr><td colspan="2">WCE = Water Crossing Engineer, SME = Subject Matter Expert, HWAP = High Water Action Plan v2024</td></tr>
</table>

Attachment B-8

Monitoring Guidelines Chart

Revised Water Crossing Scheduled Monitoring Guidelines



	Scheduled Monitoring	
Risk Category Modeled / Verified	Inspection Frequency	Scope
Event RC1	2 Years	Pro
Event RC2	2 Years	Pro
Event RC3	5 Years	Ops/Pro[1]
Event RC4	5 Years	Ops/Pro[1]
Duration	Per RA[2]	Ops/Pro[1]

1. As defined in WCP Form 4.1 - Field Inspection Plan
2. Use most conservative inspection frequency as defined by the risk assessment

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Attachment C

Angle of Attack Correction on Cross Section of Pipeline Calculation

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Angle of Attack Correction on Cross Section of Pipeline Calculation

Companion to the Bank Stability Assessment Manual
Water Crossing Program Technical User Guide Support Material

Revision 0 | December 2024

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Revision Record

Revision No.	Date Issued	Reviewed By	Description
0	12.2024	Svetlana Shafrova, EMTech	Developed angle of attack correction on cross section of pipeline calculations in support of bank stability assessment methodology for the Water Crossing Program.

Relevance

These angle of attack correction on cross section of pipeline calculations are an attachment to the *Bank Stability Assessment Manual*, which is a companion to the Water Crossing Program Technical User Guide.

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Contents

Figures

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1 Angle of Attack Correction on Cross Section of Pipeline

When a survey is completed such that the pipeline is not parallel to the crossing, an angle correction for the slope height and ratio is needed to ensure the accuracy of the measurements taken. This is because if a survey is not aligned parallel to a crossing, it can introduce errors in the angle measurements; these angle measurements need to be corrected to accurately represent the true layout of the land that was surveyed. By applying angle corrections to the points surveyed, Water Crossing Engineers can adjust for these discrepancies and provide more precise and reliable data for analysis.

To determine the Angle of Attack, first measure the length of pipe from top of banks and the channel width in the plan view of the survey as shown on Figure 1. Once the lengths have been measured, apply the lengths into the formula shown in Equation 1 to determine the Angle of Attack.

$$Angle\ of\ Attack = sin^{-1}\left(\frac{Perpendicular\ Channel\ Width}{Channel\ Width\ Along\ Pipe}\right) \qquad \text{Equation 1}$$

Use the formula shown in Equation 2 to determine the Angle of Attack.

$$Angle\ of\ Attack = asin\left(\frac{Perpendicular\ Channel\ Width}{Channel\ Width\ Along\ Pipe}\right) \times \frac{180}{\pi} \qquad \text{Equation 2}$$

Figure 1. Example Measurements of Pipe and Channel Width

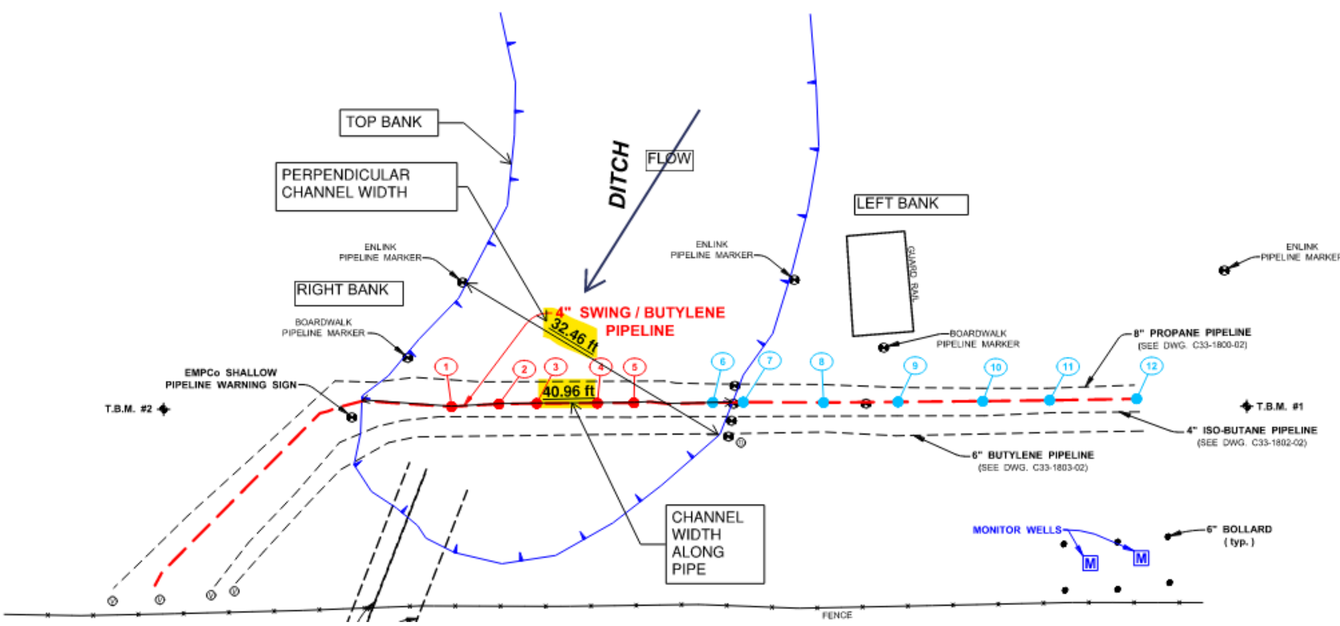

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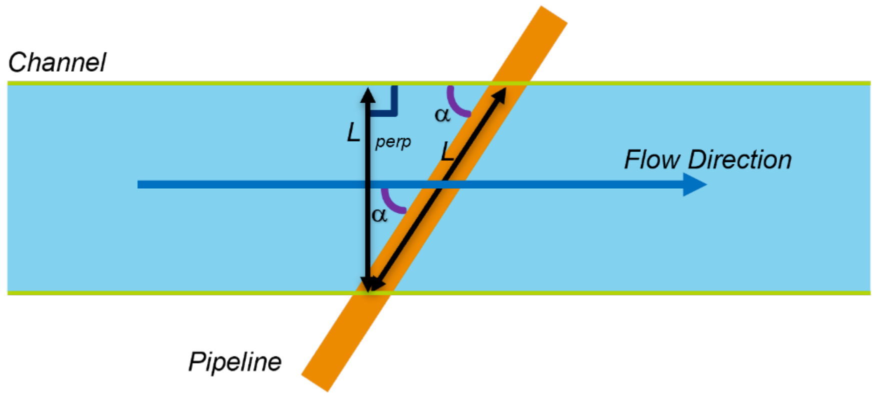
Figure 2. Example Angle of Attack Measurements



1.1 Survey Station Conversion to Whole Distances and Data Inversion to Display as Left Bank to Right Bank

Before applying the Angle of Attack onto the survey data, ensure the survey station is converted into distances and is showing data from Left Bank to Right Bank. In this example, we must first convert the survey's stationing to distances and flip (i.e., invert) the survey data to display as Left Bank to Right Bank instead of Right Bank to Left Bank. To convert the stationing to distances, the stationing must be input as a whole number and another column should subtract the Point of Vertical Intersection to the first stationing. Once the stations have been converted to distances, use the filter feature to flip the distances from largest to smallest. The next column should display the inverted distances by calculating the absolute difference between the original distances to the first original distance. Once that value is confirmed, apply the Angle of Attack to the inverted distances. In example Figure 1, the Angle of Attack is 52.4 degrees, which would be used in the formula below (Equation 3) to provide the corrected distances.

$$Corrected\ Distance = flipped\ distance \times \sin\left(radians(angle\ of\ attack)\right) \qquad \text{Equation 3}$$

An example calculation using raw survey data is presented below as Figures 3a, 3b, and 3c.

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Figure 3a. Example of Raw Station Data in Excel Workbook

Ditch 0.63 MI North of Ashland Road - wLA094aDitchNorthAshlandRoad (1803)

PVI	Station	Northing	Easting	Existing Grade	T.O.P. Elevation	D.O.C.
W1	1368+29.00	615304.86	3386476.67	18.23	10.87	7.36
W2	1368+32.00	615305.71	3386479.54	18.39	10.86	7.53
W3	1368+35.00	615306.54	3386482.43	18.52	10.86	7.66
W4	1368+38.00	615307.33	3386485.32	18.63	10.86	7.77
W5	1368+41.00	615308.13	3386488.21	18.54	10.91	7.63
W6	1368+44.00	615308.86	3386491.12	18.45	10.96	7.49
W7	1368+47.00	615309.24	3386494.07	18.18	11.06	7.12
W8	1368+50.00	615309.10	3386497.06	15.74	11.24	4.50
W9	1368+53.00	615308.63	3386499.99	13.37	11.43	1.94
W10	1368+56.00	615307.42	3386502.72	11.52	11.64	-0.12
W11	1368+59.00	615305.86	3386505.29	11.39	11.90	-0.51
W12	1368+62.00	615304.31	3386507.85	11.29	12.18	-0.89
W13	1368+65.00	615302.75	3386510.42	11.53	12.48	-0.95
W14	1368+68.00	615301.20	3386512.99	11.78	12.74	-0.96
W15	1368+71.00	615299.64	3386515.55	12.01	12.99	-0.98
W16	1368+74.00	615298.09	3386518.12	12.35	13.21	-0.86
W17	1368+77.00	615296.53	3386520.68	13.17	13.43	-0.26
W18	1368+80.00	615294.95	3386523.23	14.73	13.60	1.13
W19	1368+83.00	615293.38	3386525.79	15.75	13.78	1.97
W20	1368+86.00	615291.81	3386528.35	17.11	13.96	3.15
W21	1368+89.00	615290.25	3386530.90	17.99	14.07	3.92
W22	1368+92.00	615288.69	3386533.47	18.40	14.14	4.26
W23	1368+95.00	615287.15	3386536.04	18.36	14.16	4.20
W24	1368+98.00	615285.61	3386538.62	18.55	14.18	4.37
W25	1369+01.00	615284.01	3386541.16	18.67	14.21	4.46
W26	1369+04.00	615282.30	3386543.62	18.57	14.26	4.31
W27	1369+07.00	615280.58	3386546.07	18.73	14.31	4.42
W28	1369+10.00	615278.98	3386548.61	18.75	14.31	4.44
W29	1369+13.00	615277.44	3386551.19	18.63	14.29	4.34
W30	1369+16.00	615275.91	3386553.76	18.61	14.27	4.34
W31	1369+19.00	615274.37	3386556.34	18.72	14.24	4.48
W32	1369+22.00	615272.85	3386558.93	18.64	14.22	4.42
W33	1369+25.00	615271.32	3386561.51	18.56	14.20	4.36
W34	1369+28.00	615269.77	3386564.08	18.72	14.15	4.57
W35	1369+31.00	615268.22	3386566.65	18.62	14.08	4.54
W36	1369+34.00	615266.67	3386569.22	18.52	14.02	4.50

RAW STATION DATA

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Figure 3b. Example of Station Data as Whole Numbers and Raw Distance Data in Excel Workbook

Ditch 0.63 MI North of Ashland Road - wLA094aDitchNorthAshlandRoad (1803)

PVI	Station	Northing	Easting	Distances	Existing Grade	T.O.P. Elevation	D.O.C.
W1	136829	615304.86	3386476.67	0.00	18.23	10.87	7.36
W2	136832	615305.71	3386479.54	3.00	18.39	10.86	7.53
W3	136835	615306.54	3386482.43	6.00	18.52	10.86	7.66
W4	136838	615307.33	3386485.32	9.00	18.63	10.86	7.77
W5	136841	615308.13	3386488.21	12.00	18.54	10.91	7.63
W6	136844	615308.86	3386491.12	15.00	18.45	10.96	7.49
W7	136847	615309.24	3386494.07	18.00	18.18	11.06	7.12
W8	136850	615309.10	3386497.06	21.00	15.74	11.24	4.50
W9	136853	615308.63	3386499.99	24.00	13.37	11.43	1.94
W10	136856	615307.42	3386502.72	27.00	11.52	11.64	-0.12
W11	136859	615305.86	3386505.29	30.00	11.39	11.90	-0.51
W12	136862	615304.31	3386507.85	33.00	11.29	12.18	-0.89
W13	136865	615302.75	3386510.42	36.00	11.53	12.48	-0.95
W14	136868	615301.20	3386512.99	39.00	11.78	12.74	-0.96
W15	136871	615299.64	3386515.55	42.00	12.01	12.99	-0.98
W16	136874	615298.09	3386518.12	45.00	12.35	13.21	-0.86
W17	136877	615296.53	3386520.68	48.00	13.17	13.43	-0.26
W18	136880	615294.95	3386523.23	51.00	14.73	13.60	1.13
W19	136883	615293.38	3386525.79	54.00	15.75	13.78	1.97
W20	136886	615291.81	3386528.35	57.00	17.11	13.96	3.15
W21	136889	615290.25	3386530.90	60.00	17.99	14.07	3.92
W22	136892	615288.69	3386533.47	63.00	18.40	14.14	4.26
W23	136895	615287.15	3386536.04	66.00	18.36	14.16	4.20
W24	136898	615285.61	3386538.62	69.00	18.55	14.18	4.37
W25	136901	615284.01	3386541.16	72.00	18.67	14.21	4.46
W26	136904	615282.30	3386543.62	75.00	18.57	14.26	4.31
W27	136907	615280.58	3386546.07	78.00	18.73	14.31	4.42
W28	136910	615278.98	3386548.61	81.00	18.75	14.31	4.44
W29	136913	615277.44	3386551.19	84.00	18.63	14.29	4.34
W30	136916	615275.91	3386553.76	87.00	18.61	14.27	4.34
W31	136919	615274.37	3386556.34	90.00	18.72	14.24	4.48
W32	136922	615272.85	3386558.93	93.00	18.64	14.22	4.42
W33	136925	615271.32	3386561.51	96.00	18.56	14.20	4.36
W34	136928	615269.77	3386564.08	99.00	18.72	14.15	4.57
W35	136931	615268.22	3386566.65	102.00	18.62	14.08	4.54
W36	136934	615266.67	3386569.22	105.00	18.52	14.02	4.50

RAW STATION DATA AS WHOLE NUMBERS

CONVERT THE STATIONS TO DISTANCES BY USING THE FORMULA SHOWN BELOW. DRAG DOWN THE CELL WITH THE FORMULA TO BE APPLIED TO ALL STATIONS, SUCH THAT THE FIRST STATION IS ON CELL B5.

=B5-B5

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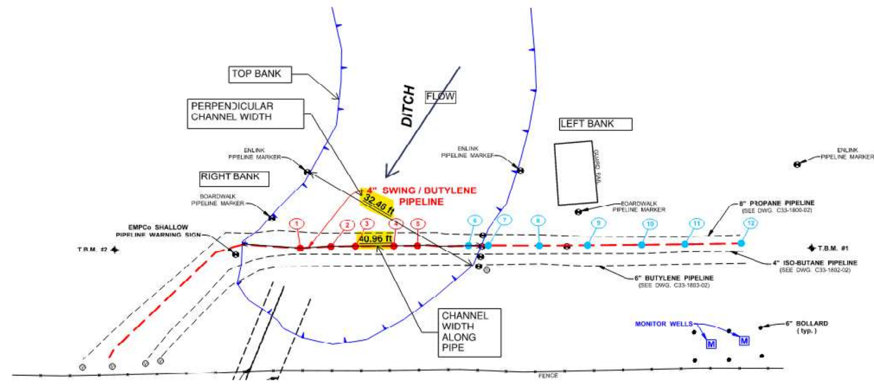
Figure 3c. Example of Distance and Station Data Corrections in Excel Workbook

APPLY FILTER TO FLIP (i.e., INVERT) THE DATA TO DISPLAY AS LEFT BANK TO RIGHT BANK (RATHER THAN AS RIGHT BANK TO LEFT BANK).

Unflipped Distance	Flipped Distance	Corrected Distance	Existing Grade	Code	T.O.P. Elevation	D.O.C.
105	0	0.00	18.52	LFP	14.02	4.5
102	3	2.38	18.62	LFP	14.08	4.54
99	6	4.75	18.72	LFP	14.15	4.57
96	9	7.13	18.56	LFP	14.2	4.36
93	12	9.51	18.64	LFP	14.22	4.42
90	15	11.88	18.72	LFP	14.24	4.48
87	18	14.26	18.61	LFP	14.27	4.34
84	21	16.64	18.63	LFP	14.29	4.34
81	24	19.01	18.75	LFP	14.31	4.44
78	27	21.39	18.73	LFP	14.31	4.42
75	30	23.77	18.57	LFP	14.26	4.31
72	33	26.14	18.67	LFP	14.21	4.46
69	36	28.52	18.55	LFP	14.18	4.37
66	39	30.90	18.36	LFP	14.16	4.2
63	42	33.27	18.4	LFP	14.14	4.26
60	45	35.65	17.99	C	14.07	3.92
57	48	38.03	17.11	C	13.96	3.15
54	51	40.40	15.75	C	13.78	1.97
51	54	42.78	14.73	C	13.6	1.13
48	57	45.16	13.17	C	13.43	-0.26
45	60	47.53	12.35	C	13.21	-0.86
42	63	49.91	12.01	C-LToB	12.99	-0.98
39	66	52.29	11.78	C	12.74	-0.96
36	69	54.66	11.53	C	12.48	-0.95
33	72	57.04	11.29	C	12.18	-0.89
30	75	59.42	11.39	C	11.9	-0.51
27	78	61.79	11.52	C	11.64	-0.12
24	81	64.17	13.37	C-RToB	11.43	1.94
21	84	66.55	15.74	C	11.24	4.5
18	87	68.92	18.18	C	11.06	7.12
15	90	71.30	18.45	RFP	10.96	7.49
12	93	73.68	18.54	RFP	10.91	7.63
9	96	76.05	18.63	RFP	10.86	7.77
6	99	78.43	18.52	RFP	10.86	7.66
3	102	80.81	18.39	RFP	10.86	7.53
0	105	83.18	18.23	RFP	10.87	7.36

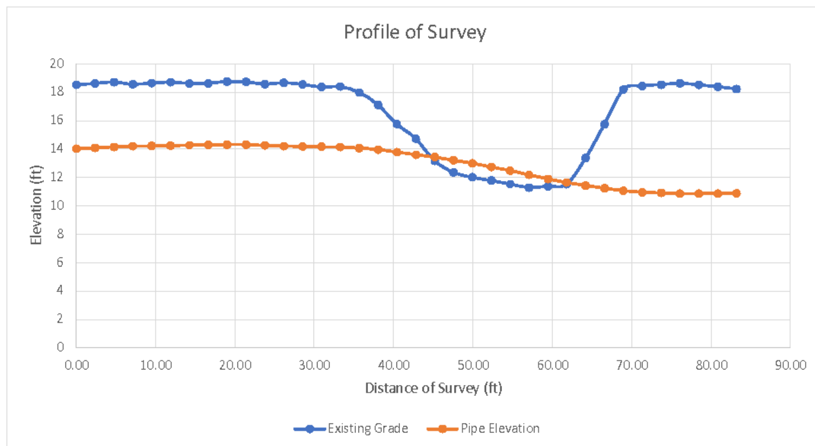
USE THE FORMULA SHOWN BELOW TO DETERMINE THE CORRECTED DISTANCE IN EXCEL WORKBOOK.

$$Corrected\ Distance = flipped\ distance\ \times \sin(radians(Angle\ of\ Attack))$$



$$Angle\ of\ Attack = asin\left(\frac{Perpendicular\ Channel\ Width}{Channel\ Width\ Along\ Pipe}\right) \times \frac{180}{\pi}$$

Perpendicular Channel Width	32.45 ft
Channel Width Along Pipe	40.96 ft
Angle of Attack	52.4 º



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Attachment D

Guidance on Slope Failure Mechanisms and Stability Hazard Assessment

ExxonMobil Technology and Engineering

Guidance on Slope Failure Mechanisms and Stability Hazard Assessment

Asset Integrity Guidance for Pipeline Operations Management – Water Crossing Program Technical User Guide Support Material

Revision 1 | December 2024

DRAFT

Revision Record

Revision No.	Date Issued	Reviewed By	Description
0	12.2017	Roberto Landazuri, EMPCo	Developed guidance on slope failure mechanisms for the Global Pipeline Integrity Water Crossing Program in collaboration with Geohazard Lead.
1.0	12.2024	Svetlana Shafrova, EMTech WCP SME T.N.	Incorporated learnings from over 2 years of application of the bank stability assessment procedures; added stability analyses results in Appendix C that show factor of safety contours to aid identification of the 1.5 factor of safety surface; updated the Slope Stability Matrix for Pipeline Water Crossings in Appendix E.

Contents

Tables

Figures

Appendices

Executive Summary

This document provides guidance on assessing embankment slope stability at pipeline water crossings by visual field inspection and desktop review of pipeline setback. A field inspection form is developed to assess slope stability based on embankment material, slope ratio and height. Specific observations of stability issues such as seepage or erosion are also included in the form to help identify potential or developing instability. The field inspection and desktop review are combined into a matrix to identify appropriate actions for the Water Crossing Engineer (WCE) and Subject Matter Expert (SME).

Slope stability factors of safety are estimated in the inspection form from curves developed with stability analysis performed on varying material, slope ratio and height. Detailed documentation for the development of these curves is provided with an explanation of general slope failure mechanics and the theory used for evaluating soil stability in slopes. Guidance is provided for the interpretation of field observations that may indicate increased potential for slope failures. Photographs and figures of specific conditions that may indicate or lead to slope instability are included as an appendix. Plates of the slope stability models with factor of safety contours allow the location of the buried pipeline relative to the required 1.5 factor of safety failure surface to be determined.

This document was originally produced in 2017 and updated in 2024 with new stability analyses results in Appendix C that show factor of safety (FS) contours to allow the WCE to find the 1.5 FS surface. The Slope Stability Matrix for Pipeline Water Crossings in Appendix E was replaced with the 2024 version.

1 Introduction

This document and the tools presented are developed to provide guidance on assessing embankment slope stability at pipeline water crossings. These tools are developed for the Global Pipeline Integrity (GPI) Water Crossing Program (WCP) to enhance the evaluation of risk associated with slope stability failures at water crossings or other slopes that can adversely impact the pipeline. Slope failure can result in significant structural damage if the sliding mass of embankment soil crushes, separates or displaces a pipeline. Streamflow poses a secondary risk to a pipeline by potentially destabilizing the stream banks by scour or reducing soil strengths. Assessments using these tools and guidelines help to simplify decision making and reduce risk by establishing action levels triggered by field inspections and desktop reviews. The assessment tools are intended for screening and are intentionally conservative to trigger further investigation by qualified personnel where questionable conditions may exist.

2 Slope Failure Mechanisms

A slope failure occurs when the embankment is no longer in mechanical equilibrium because forces that are driving movement exceed the forces that serve to resist the movement. The driving forces are the weight of the upslope soils and water (and potentially structures or live loads). Resisting forces are the shear strength of the soil along the slippage plane and any weight and water forces on the lower portion of the slope. The slope stability factor of safety (FS) is the ratio of resisting forces to the driving forces. FS values less than 1 may be associated with imminent failure, while FS values significantly greater than 1 generally indicate stable conditions. In engineering terms, slide denotes the downward and outward displacement of slope material along a plane in a shearing movement.

Soil materials such as clay comprise fine particles that, depending on loading conditions, may resist shear forces by chemical bonds between the particles characterized as cohesion. Because these materials comprise fine particles, they generally do not drain freely, and permeability as compared to coarser grained soils is low. Sands generally comprise larger-sized or coarser grained particles. The individual sand particles or “grains” can be seen with the naked eye and these materials are referred to as granular. Granular materials have little to no cohesion and resist shear forces by friction between the soil particles. Therefore, granular materials are sometimes called frictional materials. Granular materials generally drain freely, and their relative permeability is high.

Some soil materials exhibit both cohesive and frictional behavior or may change behavior based on water content or pore pressures within the soil matrix. In engineering terms, the application of external forces to a soil mass is called loading. The shear strength of some materials depends on how quickly loading is applied. Shear strengths of soils may be governed by total stress strength envelopes, also called undrained strengths. Alternatively, effective stress strength envelopes may govern shear strengths, also called effective strengths. Effective stress is the total stress minus any pore pressure. Changes in loading conditions may cause pore pressures to increase. If loading changes faster than pore pressures dissipate, undrained loading occurs and undrained strengths govern. This condition may develop if floodwaters in the stream quickly recede. If the material drains freely or changes in loading conditions occur slowly enough for pore pressures to dissipate, effective strengths govern. Undrained strengths are generally lower than effective stress strengths.

Changes in streamflow or groundwater level may raise the phreatic surface within the slope. Increases to the phreatic surface elevation reduce effective stresses within the slope which in turn may reduce effective strengths of some materials and cause failures/slides. Therefore, slope stability can be highly dependent on phreatic conditions. A summary of external and/or hydro-technical factors that can contribute to bank instability are listed below.

1. Increases to phreatic surface within the slope which may reduce effective stresses and reduce effective strengths of some materials.
2. Rapid drawdown of flood waters can lead to undrained loading conditions. Undrained strengths are generally lower and more likely to result in slope failure.
3. Uncontrolled overland flow from the floodplain erodes the high bank from the top.
4. Ponded water on the floodplain saturates the bank slope.
5. General scour occurs at the toe of the bank during flood events.
6. Floating debris or ice carried by the current causes local erosion or scour along the bank.
7. Loss of vegetation and the stabilizing effect of a root system.
8. Shrinking and softening of cohesive clays occurs during long term drought.
9. Previously disturbed soil during construction or inadequately compacted trench backfill results in low strength zones (which conventionally laid / trenched pipes will have, and HDD may not).

Slides can be classified as rotational slides or translational slides based on the shape of the failure surface and the configuration of the sliding mass. Rotational slides are characterized by the following:

1. Circular rupture surface
2. Distinct vertical scarp at the crown
3. One or more benches or bulges on surface of a moving mass
4. Cracks, mostly normal to direction of movement
5. Prominent bench or bulge at toe of slide

Translational slides are characterized by movement along a relative plane failure surface, approximately paralleling the surface of the slope or along defined horizontal stratigraphy at depth. Depth of failure may vary from a few inches to many feet. Shallow translational slides are sometimes called sloughs or creep and are typically less threatening than deeper rotational slides. Such shallow failures represent maintenance issues and typically do not affect overall stability if properly maintained. Translational slides can also be catastrophic if the failure is deep. Deep translational failures can develop along a weak stratum of dissimilar material which is commonly encountered in alluvial deposits or other environments with heterogenous soil stratification.

3 Field Inspection and Interpretation

The pipeline inspector must identify conditions in the field that may lead to slope failures. The inspection criteria and guidance process have been developed to support observations that better predict potential slope instability. In some cases, these predictions may require further investigation. Incorporating geotechnical criteria into the inspection observation will increase understanding of the hazards and help to decrease the risk of pipeline damage resulting from unexpected slope failure at pipeline water crossings.

Many triggers of slides consist of internal and external driving forces that can be observed in the field. External forces include an increase in slope angle, the removal of support (mass) low on the slope, the addition of mass high on the slope (i.e. load on crest), and the removal or absence of vegetation. External forces can be documented by checking the bank slope angles, examining the toe for signs of erosion, noting any changes to loading on the crest, and documenting changes in vegetation. Internal conditions within the stream embankment typically cannot be visually identified. These conditions may include weaker material at depth, saturation by excess water, and softening of cohesive soils. If visible, wet areas or seepage on the bank slopes should be documented. The focus of the inspections should be on the external driving forces and the soil properties of the stream banks and the specific conditions listed on the checklist that may indicate issues.

The field observation inputs include visually estimating soil type and strength (noted as stiffness or density) based on additional guidance to be provided by this study. Clayey soil has strength related to cohesion while granular material is evaluated by density and cementation. Weakly cemented silt, sand and gravel are more likely to move or flow around pipelines or vertical supports, but may still cause damage. Cohesive, clayey soil often moves downward uniformly and may apply larger forces to buried structures in its path.

4 Site Background

4.1 Field Observations

Observations and inspection for the following list of items should be performed by the field staff. A brief description of these items and their significance is included in the list and example pictures and figures for the observations are included in Appendix A.

1. Slope angle and bank height: (Appendix A, Figure 1) These are important inputs for the stability assessment and attempts should be made to estimate these as accurately as possible. However, it may not be practical for the field inspector to carry equipment to accurately measure this and judgment is required. The slope angle is measured as horizontal to vertical (H:V) and normalized as the number of horizontal feet to one vertical foot. (e.g. 2H:1V, 4H:1V). The height of the slope is the vertical distance from the bottom of the slope where it becomes flatter to the crest of the slope where it starts to flatten.
2. Soil characteristics (soil type and stiffness or density): See training document for procedure (Reference 1). Record dominant material type (sand or clay) and consistency (soft, stiff, loose, dense).
3. Scarp, bulging or caving at crest or toe (displacement): (Appendix A, Figures 2 and 3) This indicates a slide has occurred and the slope may still be actively moving.
4. Cracks with displacement: (Appendix A, Figures 4 and 5) Cracks may be perpendicular or parallel. Movement may be horizontal or vertical. Crack location and depth should be noted.
5. Undercutting from scour or erosion: (Appendix A, Figures 6, 7, and 8) Undercutting from erosion and scour can result in an overhang. Eventually the overhang may collapse, and undercutting can progress.
6. Presence and condition of vegetation: (Appendix A, Figures 9, 10, and 11) Is the slope fully vegetated, partially vegetated or bare.
7. Animal burrows along slope: (Appendix A, Figures 12 and 13) Location, diameter, and number of burrows in area of pipeline should be documented. If known, indicate type of animal.

8. Channel incision creating taller slopes: (Appendix A, Figure 14) Lowering of streambed by erosion may increase bank height and instability. Bank height increases are difficult to determine because of changing sediment levels. Degradation also decreases depth of cover on pipelines.
9. Seepage/water exiting from the slope face or ponded water on bank/floodplain: (Appendix A, Figure 15): Seepage or springs along slope may be indicated by different or lush vegetation such as cattails or patches or greener or taller vegetation. Flow and location should be noted as well as if the discharge is muddy or clear.
10. Depressions along or near buried pipeline (Appendix A, Figures 16 and 17) Document presence of depressions or “sinks” along or near pipeline.
11. Ponding of water on the flood plain indicates clayey, poorly drained soils (Appendix A, Figures 18 and 19).

4.2 Field Inspection Checklist

The field inspection checklist is provided to allow the inspector to enter the field observations. The inspection checklist is an Excel spreadsheet, a copy of which is presented in Appendix B. The WCE will need to either assist or populate the question that asks whether the slope has the potential to ever be inundated. If not known, Arcadis recommends the assumption assume that it may become inundated.

Inputs from the Bank Stability section of the checklist are transferred to the Scoring Sheet after parameters have been verified and validated by the WCE. The Score Card is described in detail in Section 6 of the Exxon Bank Stability Procedure document.

Slope stability is part of the evaluation, question numbers 1 through 4, and charts have been created with factors of safety (FOS) of 1.1, 1.3 and 1.5. Below a FOS of 1.1 is considered red, between FOS of 1.1 and 1.3 is considered yellow, between FOS of 1.3 and 1.5 is considered light green, and above FOS of 1.5 is considered green. These FOS trend lines have formulae built into the spreadsheet, and a graphical representation is presented on pages 3 through 5 of Appendix B. Further description of the slope stability analyses is presented in the following section of this report. Question numbers 5 through 13 are specific conditions that could be considered a yellow or red condition has shown in the explanation of the bank stability scoring sheet in Appendix B. The scoring spread sheet is configured so that if any one question triggers an unstable condition, then the score is considered red. If there are no unstable conditions, but if there is one conditionally stable condition then the score is considered yellow. If there are no unstable or conditionally stable conditions, then the score sheet will register a light green or green depending on the estimated FOS calculated. An example of the score sheet, taken from data collected along the Trinity River is presented in Appendix B which indicates the condition would be evaluated as unstable. The responses to the scoring system as shown on the example in Appendix B, will be further discussed in the Matrix of Slope Stability and Pipeline Vulnerability section of this report.

5 Slope Stability Factor of Safety

The infinite slope failure model is commonly used to assess stream banks. It is a simple limit equilibrium model that considers failure surfaces parallel to the ground surface. However, it is not suitable for deeper, rotational landslides.

A screening tool is developed to estimate slope stability of stream banks based on variables easily defined in the field. The slope stability FOS tool is based on a parametric analysis that was performed using variables of soil type, soil consistency, bank height, and slope angle to determine factors of safety based on typical stream bank conditions. A series of safety factor curves produced from the results allow an initial assessment of slope stability. The slope stability analyses are based on post-flood, rapid drawdown conditions where the groundwater surface remains higher than the river stage. The analyses were performed in accordance with the United States Army Corps of Engineers Engineering Manual (EM) 1110-2-1902 Slope Stability (Reference 2). Additional analysis for sandy slopes is performed using the method of pore pressure ratio to define porewater conditions in the slope.

5.1 Material Properties

Analysis of sudden drawdown slope stability requires undrained and drained strengths for materials. When lab tests are unavailable, shear strength parameters are generally based on correlations from geotechnical textbooks and engineering judgment. For this tool, clay strengths are estimated using consistency to unconfined compressive strength correlations and typical peak friction angle values. Consistency of cohesive soils is typically described as soft, medium, stiff or hard. Two consistency values, soft and stiff, are chosen for this evaluation to represent the upper and lower bounds of undrained shear strengths. These undrained strength properties, as shown in Table 1, are based on correlations provided in Terzaghi's *Soil Mechanics in Engineering Practice* (Reference 3).

Drained, effective strength values are based on correlations of soil plasticity index to internal friction angles provided by Duncan and Wright (Reference 4). Lower plasticity, lean clays are assumed to have a plasticity index (PI) of 20 while high plasticity, fat clays are assumed to have a PI of 50. Selected strength values for clays are shown in Table 1. An average total unit weight of 120 pounds per cubic foot (pcf) is assumed for all materials.

Table 1 Soil Properties for Clays

Material	Stiffness	Unit Weight (pcf)	Drained Shear Strength Properties		Undrained Shear Strength Properties	
			Friction Angle (ϕ') (degrees)	Cohesion (psf)	Friction Angle (ϕ) (degrees)	Cohesion (psf)
Lean Clay (CL) (PI = 20)	Stiff	120	30	100	0	2000
	Soft		24	100	0	500
Fat Clay (CH) (PI = 50)	Stiff		26	100	0	2000
	Soft		22	100	0	500

Granular stream bank materials are represented by clayey and silty sands at two different densities, dense and loose, with internal friction angles of 35 and 28 degrees, respectively. The friction values are based on a relative density to peak angle of internal friction correlation for uniform fine sands (Reference 4). A small amount of cohesion is necessary to produce realistic failure surfaces in the stability analysis models, otherwise the most critical failure surface would be along the bank face. Also, a sand bank with no cohesion would likely erode during a high-water event. Strength properties for sands are shown in Table 2.

Table 2 Soil Properties for Sands

Material	Density	Unit Weight (pcf)	Effective Strength Properties	
			Friction Angle (ϕ') (degrees)	Cohesion (psf)
Silty Sand/Clayey Sand (SM/SC)	Dense	120	35	100
	Loose		28	100

5.2 Stability Analysis Methodology

As part of the safety factor assessment, the slope stability analysis is conducted by a limit equilibrium procedure using Spencer's Method in GeoStudio's SLOPE/W 2007 software program. Limit equilibrium stability analysis computes a FOS using equations of static equilibrium. The stability FOS is defined with respect to the shear strength of the soil and the equilibrium shear stress. The shear strength of the soil is expressed by the Mohr-Coulomb equations for total and effective stresses (Reference 2). The equilibrium shear stress is the shear stress required to maintain the potential sliding mass just in equilibrium at the limits of failure. The FOS equals the available shear strength divided by the equilibrium shear stress. The magnitude of the FOS provides a good indicator of slope stability. FOS values less than 1 may be associated with imminent failure, while FOS values significantly greater than 1 generally indicate stable conditions.

Spencer's Method uses the method of slices to discretize a potential sliding mass into vertical slices. A circular or noncircular failure surface can be assumed; both shear and normal interslice forces for each slice are considered. The relationship between the interslice shear and normal forces is assumed to be constant between all slices and the solution satisfies both moment and force equilibrium. To satisfy vertical force, horizontal force, and moment equilibrium conditions, Spencer's Method requires an iterative computer solution. Detailed descriptions of the theory, statics equations, assumptions, and iterative methods are available in GeoStudio's Stability Modeling with GeoStudio Manual (Reference 5).

SLOPE/W is a computer program that locates the critical failure surface using a search routine in combination with search limits specified by the user. A range of potential slide geometries is specified by the user and SLOPE/W calculates a FOS for a large set of yield surfaces representing this range. Initially, a broad search area is investigated. Based on the initial results, the search area is revised and narrowed until the critical yield surface producing the lowest FOS is achieved. In the analyses for the FOS graphs, trial slip surfaces are circular-type failure surfaces. The estimated critical failure surfaces are shown as white lines in the analysis plates with FoS ranges shown in shades of colors from red to blue.

5.2.1 Sudden Drawdown Conditions

The slope stability models represent rapid drawdown of a stream or river where the water surface starts at a flood stage positioned a few feet below the crest of the bank and lowers to a few feet above the stream bottom. A phreatic surface is estimated for the upper and lower water levels with the bank remaining saturated. This assessment uses a three-stage method proposed by Duncan, Wright, et al (Reference 4, pp. G-1 to G-23). The different stages of analysis are used to determine consolidation stresses along the failure surface before and after drawdown. These stresses are used to calculate corresponding shear strengths and the FOS for stability. The method addresses shear strengths of materials that do not drain freely and may experience a reduction in strength by the rapid change in loading conditions. Additionally, the method accounts for effects of anisotropic consolidation and its influence on undrained shear strength.

The first stage of analysis is performed to estimate effective stresses along the potential failure surface prior to drawdown. Steady state conditions are assumed to exist and pore pressures for this stage are based on a phreatic surface from a stream elevation that is 3 feet below the crest. Effective stress shear strength envelopes are used for the stability analysis, and the effective normal and shear stresses at the base of each slice are calculated using Spencer's Method. The ratio of base normal to base shear stresses in this stage represents the effective principal stress ratio at consolidation (K_1).

In the second stage, two shear strength envelopes are considered to define strengths of materials that do not drain freely. The two strength envelopes represent the extremes of principal stress ratios possible. The strength envelopes include one corresponding to isotropic consolidation ($K_c = \sigma'_1/\sigma'_3 = 1$) and the other corresponding to the principal stress ratio at failure ($K_c = K_f$) which is considered the maximum ratio possible. Linear interpolation between these two strength envelopes is performed to obtain a strength envelope representing the principal stress ratio determined in the first stage (K_1). The FOS is then calculated for the second stage using the $K_c = K_1$ strength and pore water pressures from the piezometric line after drawdown is complete.

A third stage calculation is then performed to check that the completed stability analysis does not rely upon suction pore pressures. Pore pressures in the third stage are obtained from the phreatic surface assigned for the lowered pool elevation. If the undrained shear strength employed in the second stage computations is greater than the drained strength, which implies negative excess pore pressures, drained strengths are used for that portion of the slip surface and the stability is re-analyzed. The results of the third-stage of the calculation represent the factor of safety for the sudden drawdown condition.

5.2.2 Excess Pore Pressure Conditions

The sudden drawdown FOS curves for loose sands were developed from models that make assumptions for typical conditions anticipated in the field. A more conservative approach is desired for use as a screening level assessment of sandy slopes. The purpose of the additional analyses is to correlate bank height and slope angle of loose sandy soils with stability while considering vulnerability to flow liquefaction. Excess pore pressures have been shown to initiate flow liquefaction in special conditions. This stability analysis does not directly assess the susceptibility of a slope to flow liquefaction. However, the analysis may be sufficiently conservative to bracket considerations for potential flow liquefaction.

Flow liquefaction occurs when a saturated matrix of low density, fine-grained sandy material suddenly behaves undrained, excess pore pressures develop, and large deformations may occur. Normally, the strength behavior of sandy material is characterized as drained, and pore pressures in excess of steady state do not typically develop within the freely draining material. However, under special conditions, an undrained response may occur. An undrained response is observed during cyclic loading, such as from an earthquake, which may induce excess pore pressures. The increase of pore pressure and the corresponding reduction of internal friction angle initiates slope instability where sand may flow like a viscous fluid.

Three conditions are necessary for a flow slide to occur: 1) sand must be liquefiable as defined by density and grain size; 2) slope geometry must be unfavorable; and 3) an initiation mechanism must be present. In this case the initiation mechanism is increased pore pressure from sudden changes in loading. Induced pore pressures from sudden changes in loading dissipate quickly in sand. However, deformation may continue in loose sand as pore pressures increase along the initial failure surface from the contraction of the loose particles under shear stresses. This analysis develops FOS curves that address the influence of slope geometry and excess pore pressure on the stability of slopes composed of loose sand as shown in Appendix C.

The susceptibility of sand to liquefaction may be evaluated from in-situ density and grain size distribution properties that are obtained from field tests and lab analysis. Materials most susceptible to liquefaction are clean, fine sands and nonplastic, silty sands with less than 5 percent fines that are loose enough to be contractive during shear failure. The properties used in the stability analyses are the same for loose sands utilized in the sudden drawdown stability charts. The entire slope is assumed to be composed of clean, loose sand in the stability analysis because detailed geologic data is unavailable for most sites. Loose sand strength parameters are the same as provided in Table 2.

Excess pore pressures were modeled using a pore pressure coefficient. The pore pressure coefficient, r_u, is the ratio of pore water pressure to the total vertical overburden stress.

$$r_u = \frac{u}{\gamma_t H_s}$$

where:

u = the pore-water pressure

γ_t = the total unit weight

H_s = the height of the soil column

Modeling pore pressures with r_u is generally not an accurate representation of the phreatic surface in most embankments, particularly submerged slopes. However, it can provide a conservative assessment of the stability of a sandy slope using the excess pore pressure concept. The shear strength at the base of the failure surface is dependent on the effective normal stress at the base of each slice. With the r_u method, a surcharge force from the water load on the submerged slope is not included in the base stress calculation. This results in lower calculated effective stress at the base of the failure surface below a submerged slope. The lower effective base stress results in lower strength, and a more conservative stability evaluation. This is comparable to assuming pore pressures in excess of steady state conditions.

The pore pressure coefficient slope stability analysis is conducted with the same limit equilibrium procedure using Spencer's Method in GeoStudio's SLOPE/W 2007 software program. The stability models use the r_u pore-water pressure option without a piezometric line and an empty channel so that only the pore pressure ratio is used to calculate the pore pressure in each slice of the failure surface. Based on a paper provided by Exxon (Reference 6) the pore pressure coefficient can be used to model fully saturated slopes. The paper proposes two cases r_u can be used to model groundwater conditions. For Case 1, water exits the bank on the face of the saturated slope; Case 2, water exits the bank at the toe of the slope. A r_u value of 0.6 is recommended for Case 1 and an equation based on the angle of the slope is recommended for Case 2.

Case 1: $r_u = 0.6$

Case 2: $r_u = \gamma_w/\gamma_t \cos^2(\alpha)$

Figure 1 illustrates piezometric surfaces based on pore pressures calculated from r_u values. With r_u equal to 0.6 the equivalent column of water is higher than the soil mass in approximately the lower half of the slope. Because the surface load from water on the surface is not included in the base stress calculation, the r_u equal 0.6 analysis is generally more conservative than assuming a fully saturated slope with the piezometric surface at the ground surface. With r_u calculated from the equation, the equivalent column of water is higher than the soil mass only at the toe of the slope. This assumption is less conservative than assuming the piezometric surface at the ground surface. Table 3 summarizes an example of the different calculated FOS for the three pore pressure regimes through a 14-foot tall, 2H:1V slope composed of loose sand. FOS curves for r_u equal 0.6 and the calculated r_u analyses are provided in Appendix C.

Table 3 Example FOS for Loose Sand Embankment 14-feet Tall, 2H:1V Slope

Pore Pressures	FOS
$r_u = 0.6$ (Case 1)	0.95
Piezometric Surface at Ground Surface	1.07
$r_u = \frac{\gamma_w}{\gamma_t} cos^2(\alpha)$ (Case 2)	1.23

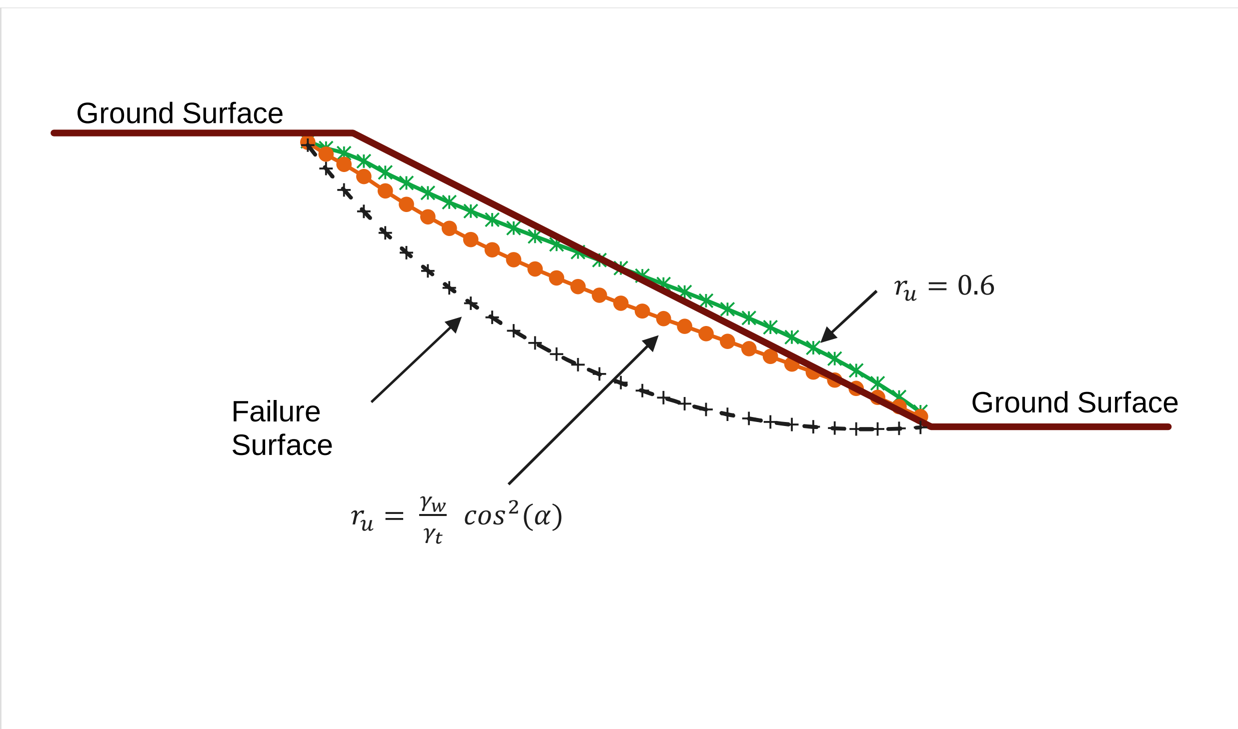

Figure 1. Piezometric Surface Derived from r_u Values

5.3 Slope Stability Parametric Analysis

The slope stability screening tool is developed from parametric slope stability analysis. A review of pipeline crossings indicates typical bank heights are 10 to 15 feet measured from the channel bottom to the high bank crest. Bank heights ranging from 10 to 28 feet with slopes ranging from 1H:1V to 4H:1V are included in the parametric analysis. Specifically, bank heights at 10, 14, 18, 20, 22 and 28 feet are addressed for six material types. Slope stability analyses under sudden drawdown conditions are executed for each bank geometry and material and the results are plotted on FOS graphs.

5.4 Slope Stability Screening Tool

Results are presented as a series of charts constructed to show overall slope stability based on geometry and soil type during sudden drawdown. The FOS does not account for erosion processes from overland flow or toe scour. The charts are intended to predict the likelihood of bank failure for the geometric conditions and soil types identified by the field inspector. Curves on the charts represent a FOS of 1.3 with conditionally stable conditions along and to the right of the curve and unstable conditions located to the left. Equations of the curves are provided in the footnotes. The graphs are included in Appendix C and form the basis of determining the probability of failure for a slope and the corresponding appropriate actions such as further screening and evaluation. These same graphs were used to develop the red, yellow, light green and green graphs presented in Appendix B.

Charts are developed for soft and dense lean clay and fat clay as well as loose and dense sand using the parameters presented in tables 1 and 2. Modifications were made to the stiff clay chart. Because this is a screening tool and field identification of soil strength has a high margin of error, the initial stiff clay chart may be unconservative. Additionally, field conditions can change, and clay can experience softening when wet. To account for potential softening of stiff clay and add additional conservatism to the screening tool, the stiff clay FOS curves are shifted. The stiff lean clay FOS curves are shifted 0.15 and the stiff fat clay FOS curves are shifted 0.25 to make these more conservative.

The FOS curves developed from drawdown analysis for sand were not considered sufficiently conservative for screening. The more conservative r_u=0.6 FOS curves are recommended for screening embankments that become inundated during flooding because they will result in flagging sandy slopes that may have marginal stability or the potential to become marginally stable. These slopes may not pose a risk to the pipeline but should be inspected by experienced engineers to properly assess if further investigation is warranted. For sandy slopes that do not become inundated during flooding the FOS curves for the r_u values calculated from the slope angle are recommended for screening.

5.5 Screening Tool Validation

To help validate the FOS curves developed for this program, a comparison to other graphical method was performed. Prior to modern computers that can quickly solve stability analysis using rigorous methods simpler methods were used that made some assumptions and ignored certain forces so that a solution could be reasonable be obtained by hand calculations. Some of these methods were also developed with charts to provide relatively quick and easy estimations of slope stability. Because many of these methods are conservative, they have been used successfully and safely for evaluation and design. Appendix D includes a technical memorandum with the comparison of the FOS curves developed using the methods described in this report to other historical chart methods. The appendix presents comparisons to methods published by Janbu in 1968 and published by Morgenstern in 1963. As expected, the older methods are more conservative but show similar trends with slope angle and height.

6 Pipeline Vulnerability

Crossings that indicate that the bank is **unstable** (red), **conditionally stable** (yellow), or **likely stable** (light green), (from Score Card or field inspection) should have slip surfaces drawn on their survey profiles to establish the proximity of the pipeline to a possible failure plane. Slip surfaces/failure planes are determined by finding the slope stability analysis result plate in the Arcadis *Guidance on Slope Failure Mechanisms and Stability Hazard Assessment* report, dated December 2017 (Appendix C) that is the closest match to the bank height, slope ratio, and soil type of the water crossing. If the crossing has a red, yellow, or light green designation (i.e., FOS <1.5), then additional slip surface representing light-green condition (FOS<1.5) should also be checked as well. The slip surface is estimated by scaling the depths of several points along the slope in the figure and transferring them to the latest water crossing survey profile (if available). If a survey profile of the subject water crossing is not available and the SME determines that the light green, yellow, or red score is credible, a Pro Survey should be requested. When the survey results become available, the scorecard and failure plane should be updated accordingly.

As-built plans may be used for this step if a survey has not been performed at the time of the evaluation. The following general steps should be followed to sketch the failure surface:

1. Select the appropriate 1.5 FOS theoretical slip surface from Appendix C corresponding to the bank height, soil type, and slope ratio corresponding to the crossing being evaluated. Example is shown in Figure 2.
2. From the theoretical curve selected from Appendix C, calculate the depth of the failure surface along four equidistant points along the bank length.
3. Adjusting the pdf and/or the profile to the same scale and tracing is also an option.
4. Transfer these measurements to the survey cross-section of the crossing and sketch a circular failure plane similar to the theoretical failure plane as shown in Figure 3.
5. Determine if the pipeline falls within the estimated failure plane or outside of it with a buffer of at least 5 feet.

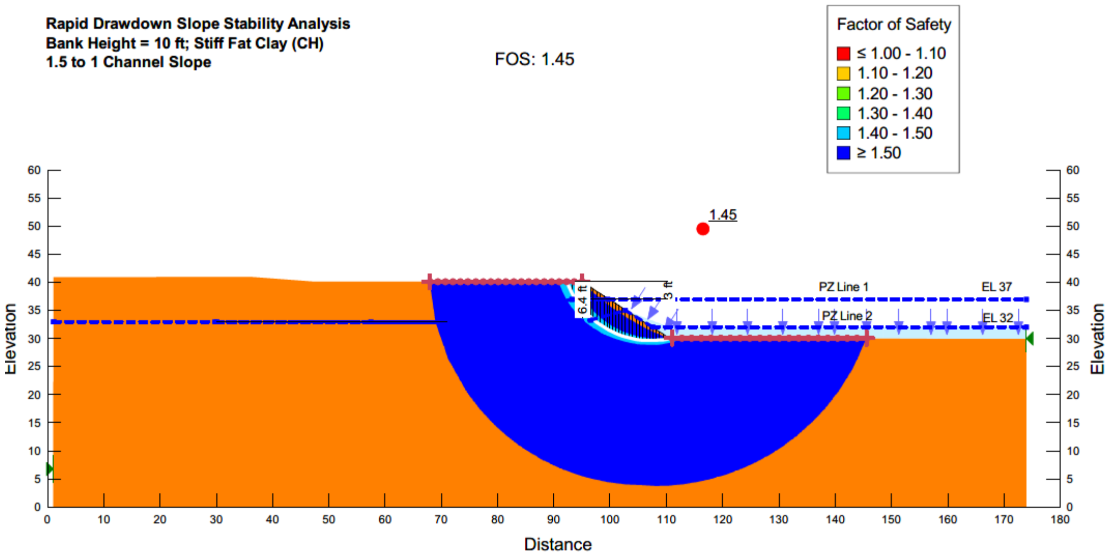

Figure 2: Example slope stability figure with theoretical slip surface

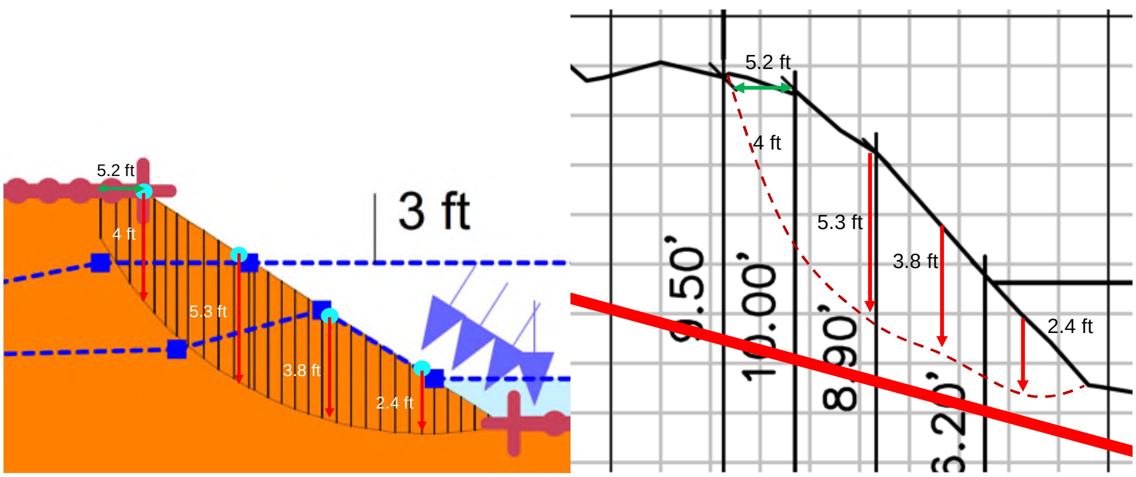

Figure 3: Example using four points to transfer slip surface to a profile

The Slope Stability Hazard Matrix is shown in Appendix E. The matrix guides the WCEs through the action items necessary to complete the bank stability assessment at pipeline water crossings. The Slope Stability Hazard Matrix requires two inputs, the Bank Stability Scorecard color category (slope vulnerability) and pipeline vulnerability. The pipeline vulnerability input is based on distance from the 1.5 FOS failure surface to the pipeline. A 5-foot minimum distance has been established as the criterion for pipeline vulnerability. If the pipeline location and setback is unknown, additional data may be required such as Operational input, survey data, and geotechnical SME guidance.

The stability models are shown with a range of FOS contours in Appendix C. The Matrix requires examination of the failure surfaces up to and including factors of safety of ***1.5*** for the rapid drawdown load case to determine if any intersect or encompass the pipeline. Thus, the failure area must be superimposed on the latest professional survey of the pipeline. The 1.5 FOS surface is found between the light blue and dark blue color contours in the plates of the models.

7 Recommendations to Supplement High Water Action Plan

Having an action plan in place prior to a high-water event provides clear and necessary emergency actions, provides opportunity to plan for implementation of these actions, and reduces time necessary for decision making during a potential emergency. By screening the water crossings with these tools, resources can be focused on the highest priority crossings which pose the greatest risk. Existing tools that help to identify concerns with scour and erosion are currently in place and provide a basis for the current High-Water Action Plan (HWAP). The tools developed and presented in this report to assess slope stability for the WCP can be used by WCEs during development of HWAPs. HWAP considerations are only considered for Action Numbers 1 and 2. During high water, embankment stability conditions may deteriorate from saturation or changes in geometry. Slopes ranked as Action Number 1 in the matrix are of highest priority and should be monitored closely. Slopes ranked as Action Number 2 are secondary and should at least be inspected in response to a high-water event. Slopes ranked as Action Number 4 should be considered to be inspected following a high-water event. Slopes ranked as Action Number 5 should have the normal WCP action performed following a high-water event. During high water it may not be possible to observe or even access channels that are inundated by flooding. Crossings ranked as Action Number 1 using these tools have the highest likelihood to experience slope failure which may directly pose an increased risk to the pipeline. Therefore, Operations should make careful consideration to possibly shut down Action Number 1 ranked pipeline water crossings during high-water events. During HWAP development (based on Action Numbers 1 and 2) WCEs should reach out to the SME for guidance regarding site specific monitoring techniques that may be considered.

8 References

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Appendix A

Field Observations Pictures and Figures

Figure 1

Slope angle and bank height. The slope angle is measured as horizontal to vertical (H:V)

Figure 2

Vertical scarp near crest or bulging at toe indicates active slide.

Figure 3

Cracks on the slope or crest may indicate movement. Cracks may be perpendicular or parallel to the crest. Movement may be horizontal or vertical. Crack location and depth should be noted.

Figure 4

Cracks on the slope or crest may indicate movement. Cracks may be perpendicular or parallel to the crest. Movement may be horizontal or vertical. Crack location and depth should be noted.

Figure 5

Cracks on the slope or crest may indicate movement. Cracks may be perpendicular or parallel to the crest. Movement may be horizontal or vertical. Crack location and depth should be noted.

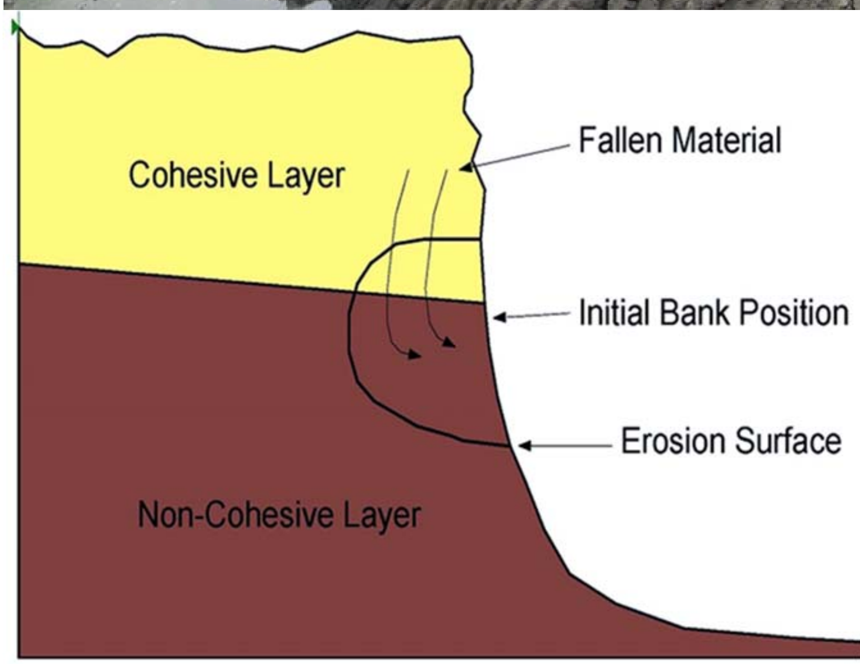


Figure 6

Schematic of bank undercutting from scour or erosion. Undercutting may result in an overhang. Eventually the overhang may collapse, and undercutting can progress.

Figure 7

Schematic of bank undercutting from scour or erosion. Undercutting may result in an overhang. Eventually the overhang may collapse, and undercutting can progress.

Figure 8

Schematic of bank undercutting from scour or erosion. Undercutting may result in an overhang. Eventually the overhang may collapse, and undercutting can progress.

Figure 9

Fully vegetated slope with grass and shrubs or mature trees.

Figure 10

Partially vegetated – mostly grass, weeds, few trees and shrubs

Figure 11

Sparse – little to no vegetation, bare

Figure 12 Schematic of effect of animal burrows on banks

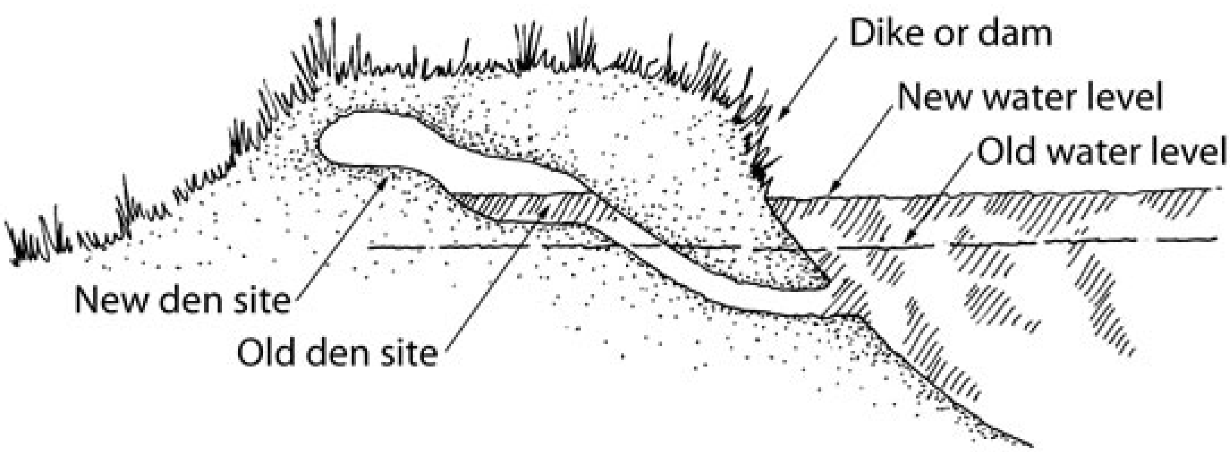


Figure 13

Location, diameter, and number of animal burrows in area of pipeline should be documented. If known, indicate type of animal.

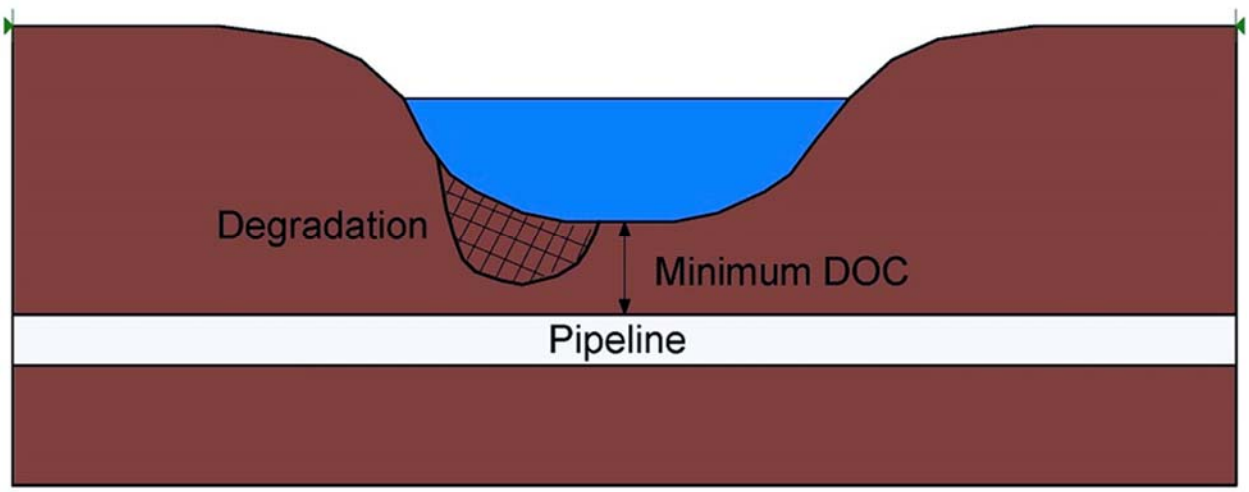


Figure 14 Lowering of streambed by erosion may increase bank height and instability. Bank height increases are difficult to determine because of changing sediment levels. Degradation also decreases depth of cover on pipelines

Figure 15

Document any seepage or springs along pipeline. These may be indicated by different vegetation such as cattails. Estimate amount of flow and note location. Is seepage clear or muddy?

Figure 16

Document presence of depressions or "sinks" along or near pipeline

Figure 17

Document presence of depressions or “sinks” along or near pipeline

Figure 18

Note any ponding of water on the flood plain. This indicates clayey, poorly drained soils.

Figure 19

Note any ponding of water on the flood plain. This indicates clayey, poorly drained soils.

Appendix B

Field Inspection Checklist and Scoring Sheets

ExxonMobil Global Pipeline Integrity **DRAFT** Rev 2

Water Crossing Program Bank Stability Site Inspection Question/Checklist

Water Crossing ID and Name ______________________________

Date Inspection Completed ________________

Date Sent to Water Crossing Program ________________

Horizontal Directional Drill (HDD) Setback Question:		**Yes**	**No**	**N/A**
1	If the pipeline at the water crossing was installed via HDD, is the setback known to be greater than 1/4 of channel width. If yes, no further inspection is required at this time.			
Floodplain and Channel Migration Questions:		**Yes**	**No**	**N/A**
1	Is a washout (a field runoff ditch or stream) near (within 150 feet upstream and downstream) or running over the top of the EMPCo ROW that drains to the main channel?			
2	Have trees along the banks fallen or are currently falling into the channel? Are tilted or curved trees growing along the slope or at the toe of the slope?			
3	Is evidence visible that the channel high bank has eroded or migrated significantly over time?			
4	Are areas with soft or disturbed ground with poor drainage and ponded water present?			
Bank Stability Questions:		**Yes**	**No**	
1	Slope Ratio and Height (first box horizontal to vertical ratio, second box height in feet)	1.4		40
2	Bank slope soil type: a) Fat clay; b) lean clay; c) silt, d) sand; e) other (describe)	a		
3	Bank slope soil strength: a) Stiff, strong or very dense; b) medium stiff or dense; c) soft, weak or loose	b		
4	Vegetation cover on slope face: a) Well vegetated with trees; b) light vegetation (mostly grass); or c) no vegetation	c		
5	Seepage from slope face: Is there evidence of groundwater seepage exiting from the slope of the banks above the typical low water line? (This is sometimes indicated by patches of different vegetation)		x	
6	Land drainage: a) Flat; b) minor drainage over slope; or c) drainage over slope with erosion gullies	a		
7	Previous landslide activity: Is evidence of recent or historical bank sloughing visible (large parts of bank have slid downward into the channel i.e. terraces)?	x		
8	Erosion: Is active erosion visible at the crossing (or upstream and downstream)?	x		
9	Undercutting: Are trees on the bank with exposed and overhanging roots?	x		
10	Are any soil cracks on the slopes or above the banks? Note if parallel or perpendicular to stream and note the amount of displacement (width).		x	
11	Are depressions or larger sinkholes within or near ROW?		x	
12	Are animal burrows present on the slope face?		x	
External Factors Questions:		**Yes**	**No**	**N/A**
1	Has the area experienced long-term drought?			
2	Has the area experienced a recent (past 3 months) flood event?			
3	Is debris buildup accumulating in the channel (especially near the toe of the bank)? Upstream or downstream?			
4	Are other pipelines upstream of the EMPCo lines within the channel?			
4a	If yes, are the upstream pipelines exposed (in air or water)?			
4b	If yes, is armoring (concrete, matting, rip-rap, palisades) known or visible?			
Monitoring Options:		**Yes**	**No**	**N/A**
1	Can pictures be taken to show upstream, downstream and pipeline crossing location? (If so, then please take pictures and include as part of this response.)			
2	Does Aerial Patrol take photos of the water crossing every 2 weeks? Or after regional flooding events?			
3	Could installing numbered monitoring stakes at 5 foot intervals at the water crossing be an option? (Stakes will help mark and identify movement of the high bank location during flooding or at least after flooding subsides).			

Left / East Bank

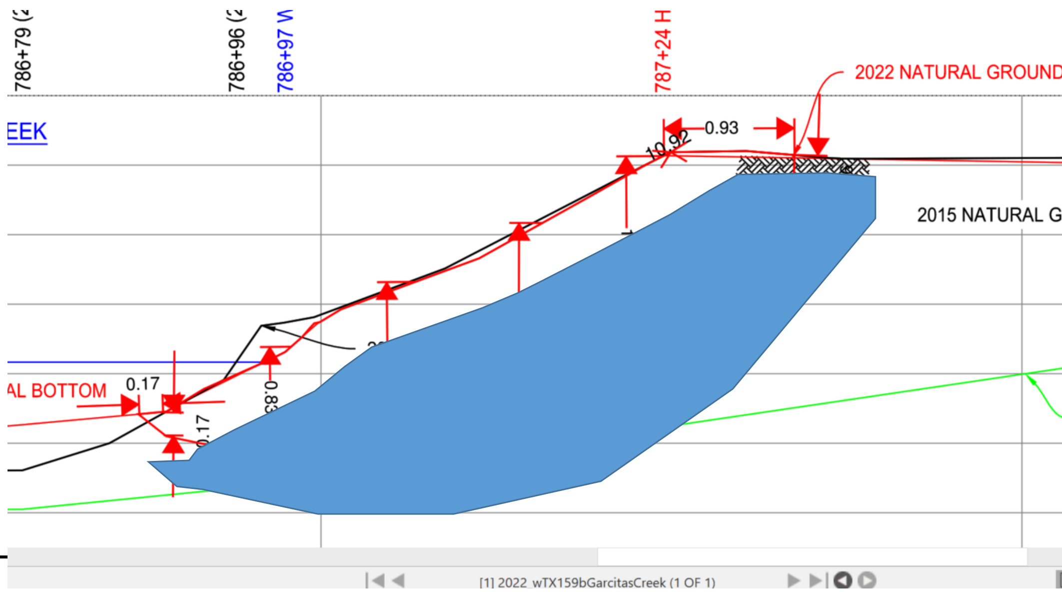
ExxonMobil Global Pipeline Integrity Revision 5

Water Crossing Program Bank Stability Site Inspection Question/Checklist

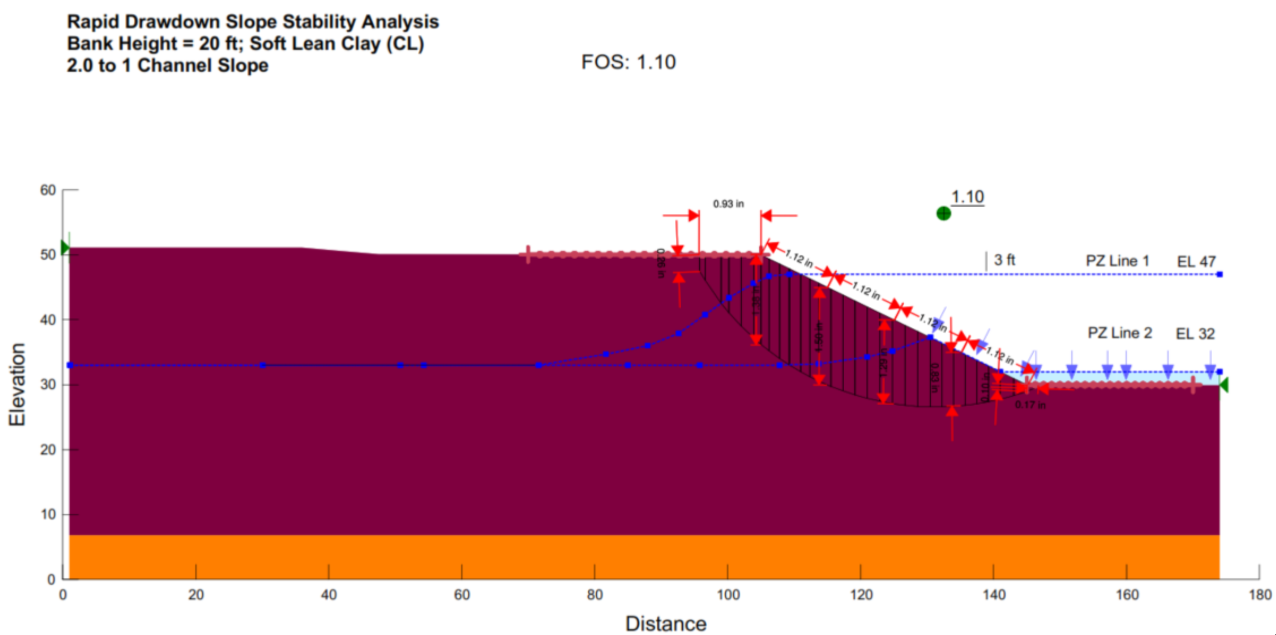
Bank Stability Questions:		Yes	No	Rationale
1	Slope Ratio and Height (first box horizontal to vertical ratio, second box height in feet)	1.9	18.7	YELLOW
2	Bank slope soil type: a) Fat clay; b) lean clay; c) silt, d) sand	b		
3	Bank slope soil strength: a) Stiff, strong or very dense; b) soft, weak or loose	b		
	FOR WCE - Can the bank ever get fully inundated	x		
4	Vegetation cover on slope face: a) Well vegetated with trees; b) light vegetation (mostly grass); or c) no vegetation	b		GREEN
5	Seepage from slope face: Is there evidence of groundwater seepage exiting from the slope of the banks above the typical low water line? (This is sometimes indicated by patches of different vegetation)		x	GREEN
6	Land drainage: a) Flat; b) minor drainage over slope; or c) drainage over slope with erosion gullies	c		YELLOW
7	Previous landslide activity: Is evidence of recent or historical bank sloughing visible (large parts of bank have slid downward into the channel i.e. terraces)?		x	GREEN
8	Erosion: Is active erosion visible at the crossing (or upstream and downstream)?	x		YELLOW
9	Undercutting: Are trees on the bank with exposed and overhanging roots?		x	GREEN
10	Are any soil cracks on the slopes or above the banks? Note if parallel or perpendicular to stream and note the amount of displacement (width).		x	GREEN
11	Are depressions or larger sinkholes within or near ROW?		x	GREEN
12	Are animal burrows present on the slope face?		x	GREEN
	SCORE			**YELLOW**

Left / East Bank

Survey Mark Up Screenshot



FOS Tool Screenshot



Right / West Bank

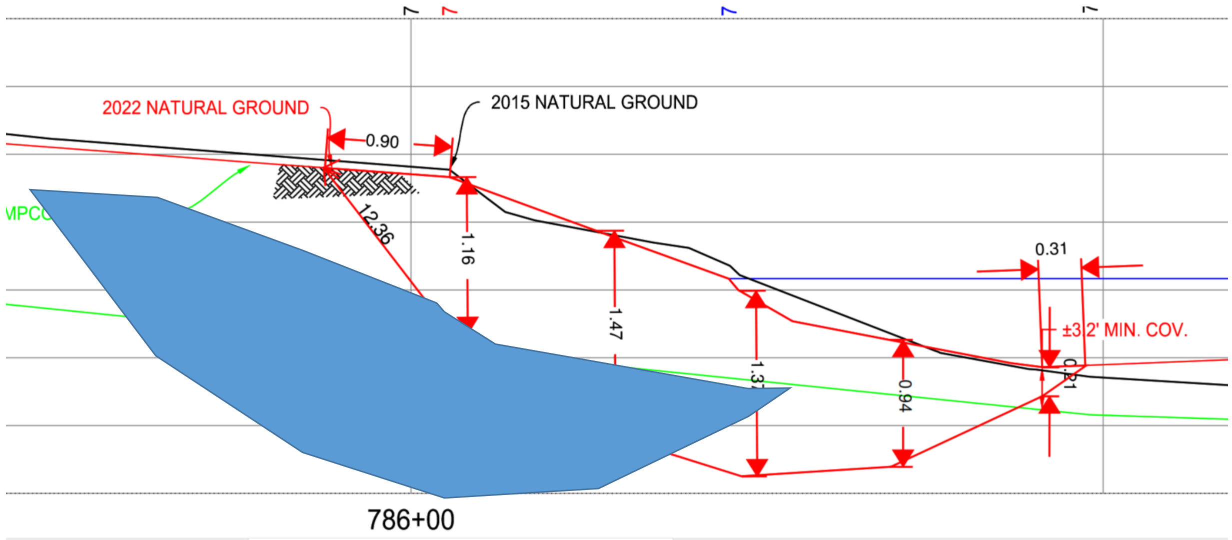
ExxonMobil Global Pipeline Integrity Revision 5

Water Crossing Program Bank Stability Site Inspection Question/Checklist

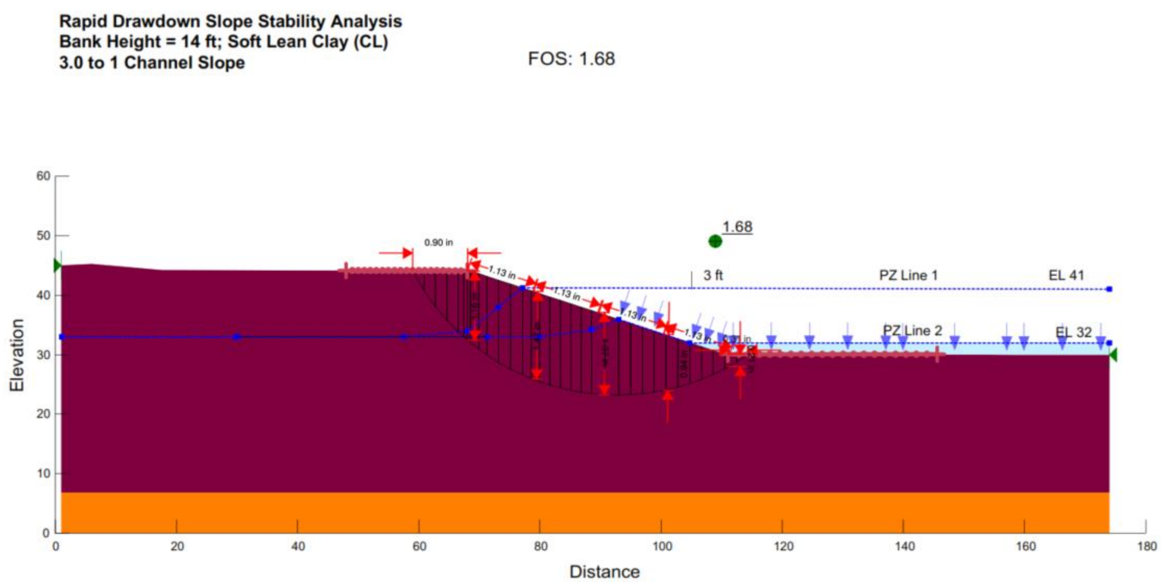
Bank Stability Questions:		Yes	No	Rationale
1	Slope Ratio and Height (first box horizontal to vertical ratio, second box height in feet)	3.0	14.2	GREEN
2	Bank slope soil type: a) Fat clay; b) lean clay; c) silt, d) sand	b		
3	Bank slope soil strength: a) Stiff, strong or very dense; b) soft, weak or loose	b		
	FOR WCE - Can the bank ever get fully inundated	x		
4	Vegetation cover on slope face: a) Well vegetated with trees; b) light vegetation (mostly grass); or c) no vegetation	a		GREEN
5	Seepage from slope face: Is there evidence of groundwater seepage exiting from the slope of the banks above the typical low water line? (This is sometimes indicated by patches of different vegetation)		x	GREEN
6	Land drainage: a) Flat; b) minor drainage over slope; or c) drainage over slope with erosion gullies	b		GREEN
7	Previous landslide activity: Is evidence of recent or historical bank sloughing visible (large parts of bank have slid downward into the channel i.e. terraces)?		x	GREEN
8	Erosion: Is active erosion visible at the crossing (or upstream and downstream)?		x	GREEN
9	Undercutting: Are trees on the bank with exposed and overhanging roots?		x	GREEN
10	Are any soil cracks on the slopes or above the banks? Note if parallel or perpendicular to stream and note the amount of displacement (width).		x	GREEN
11	Are depressions or larger sinkholes within or near ROW?		x	GREEN
12	Are animal burrows present on the slope face?		x	GREEN
	SCORE			**GREEN**

Right / West Bank

Survey Mark Up Screenshot



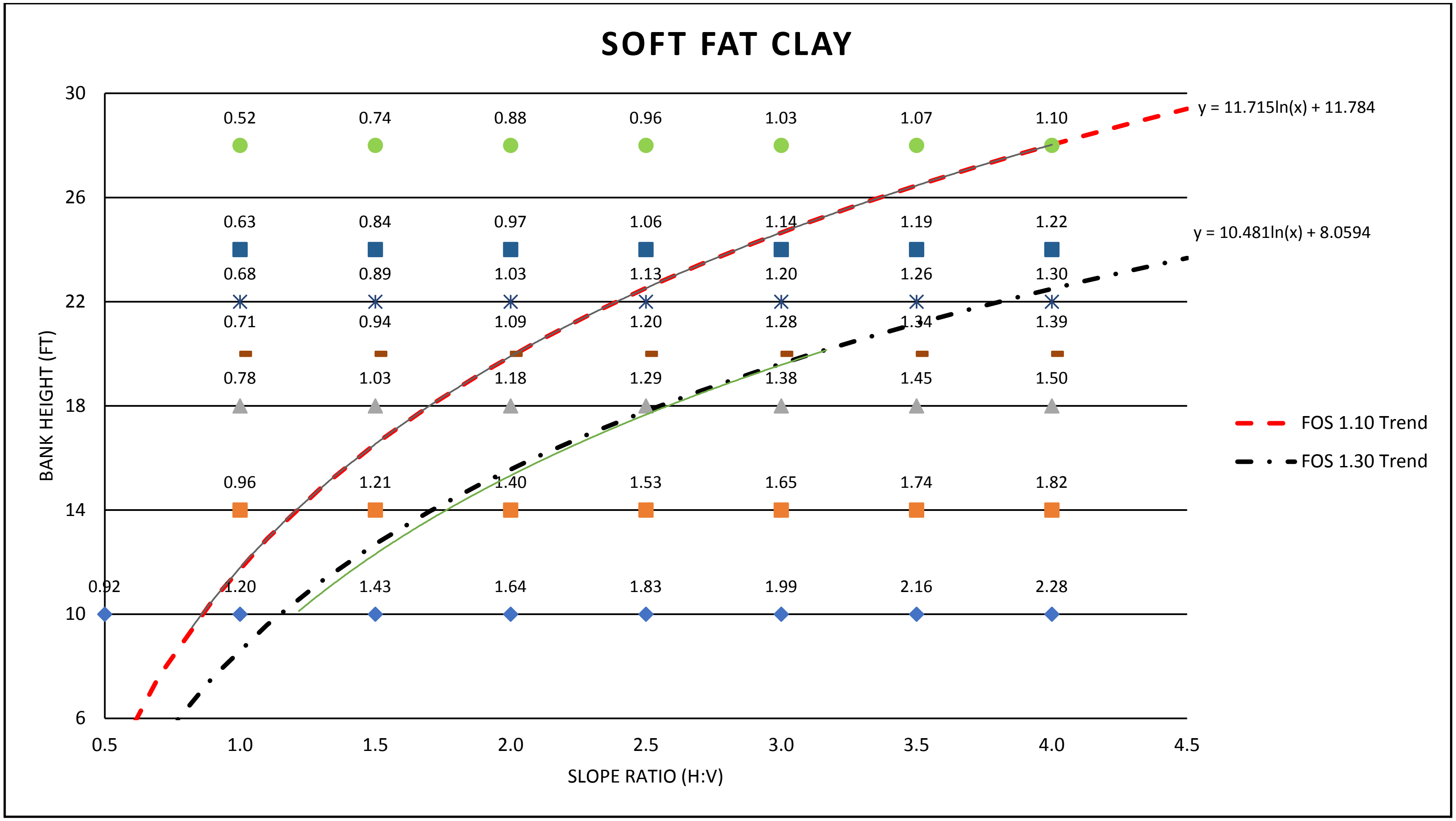
FOS Tool Screenshot



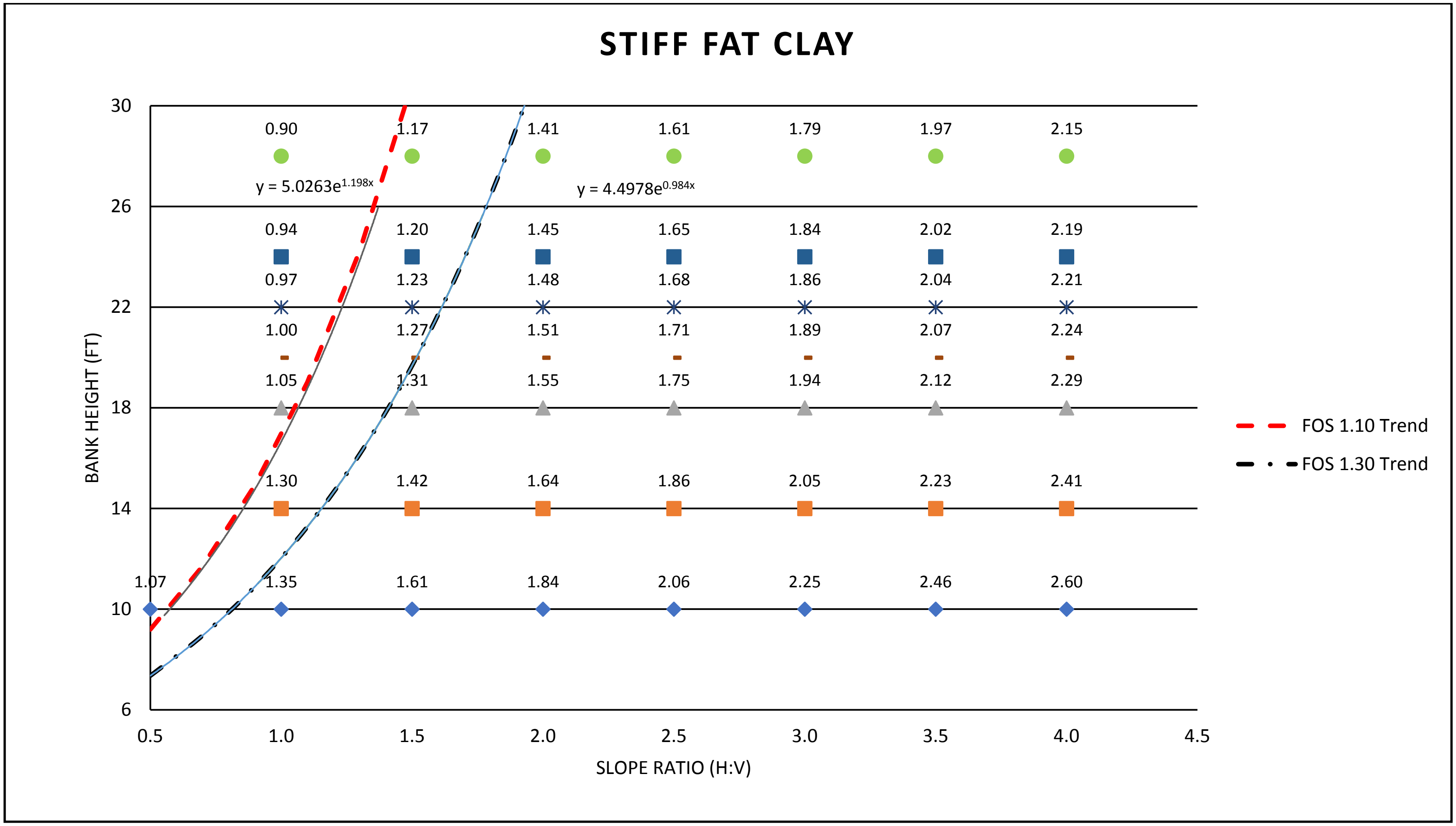
Appendix C

Slope Stability Results

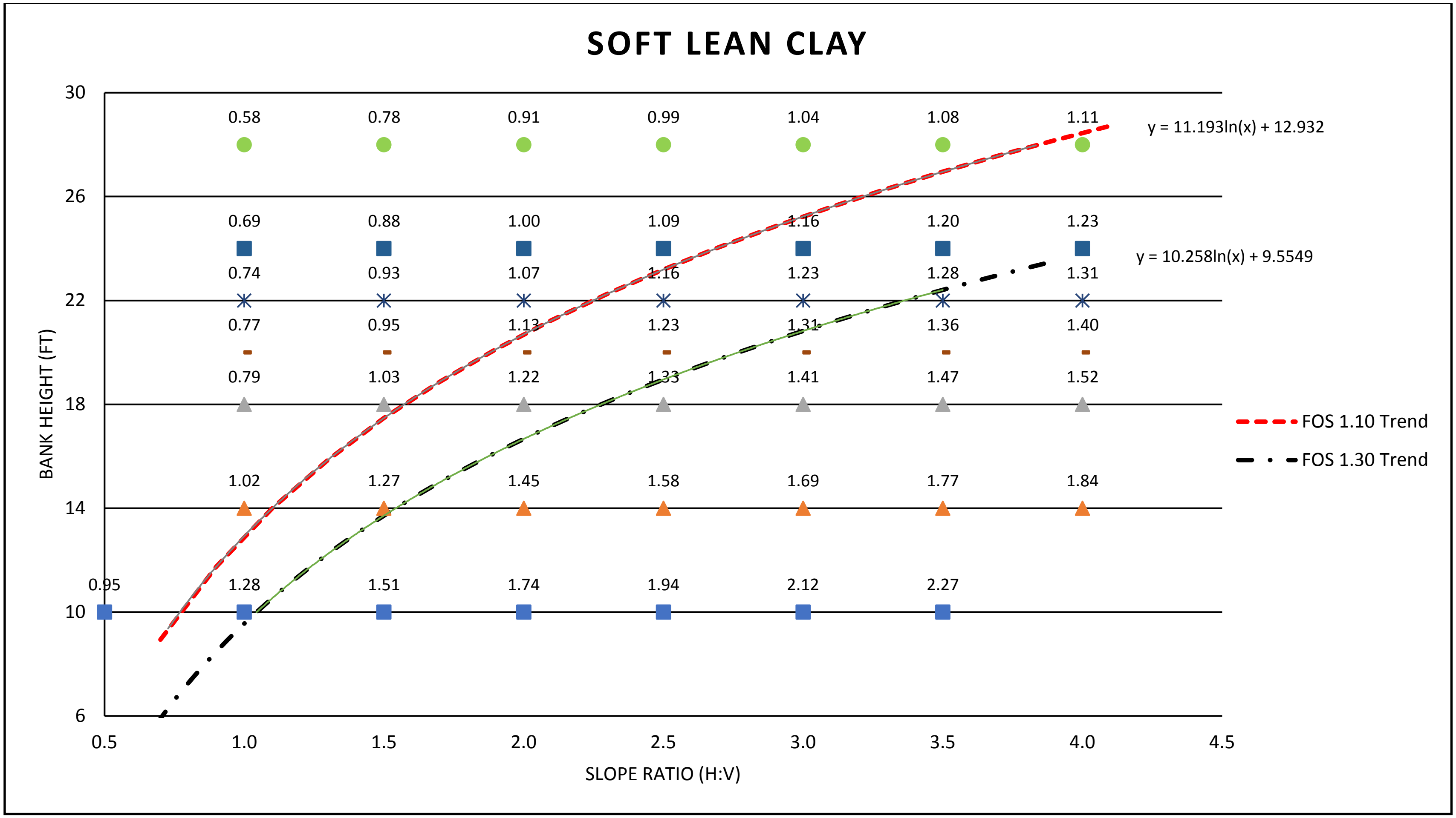
Slope Stability Result Graphs



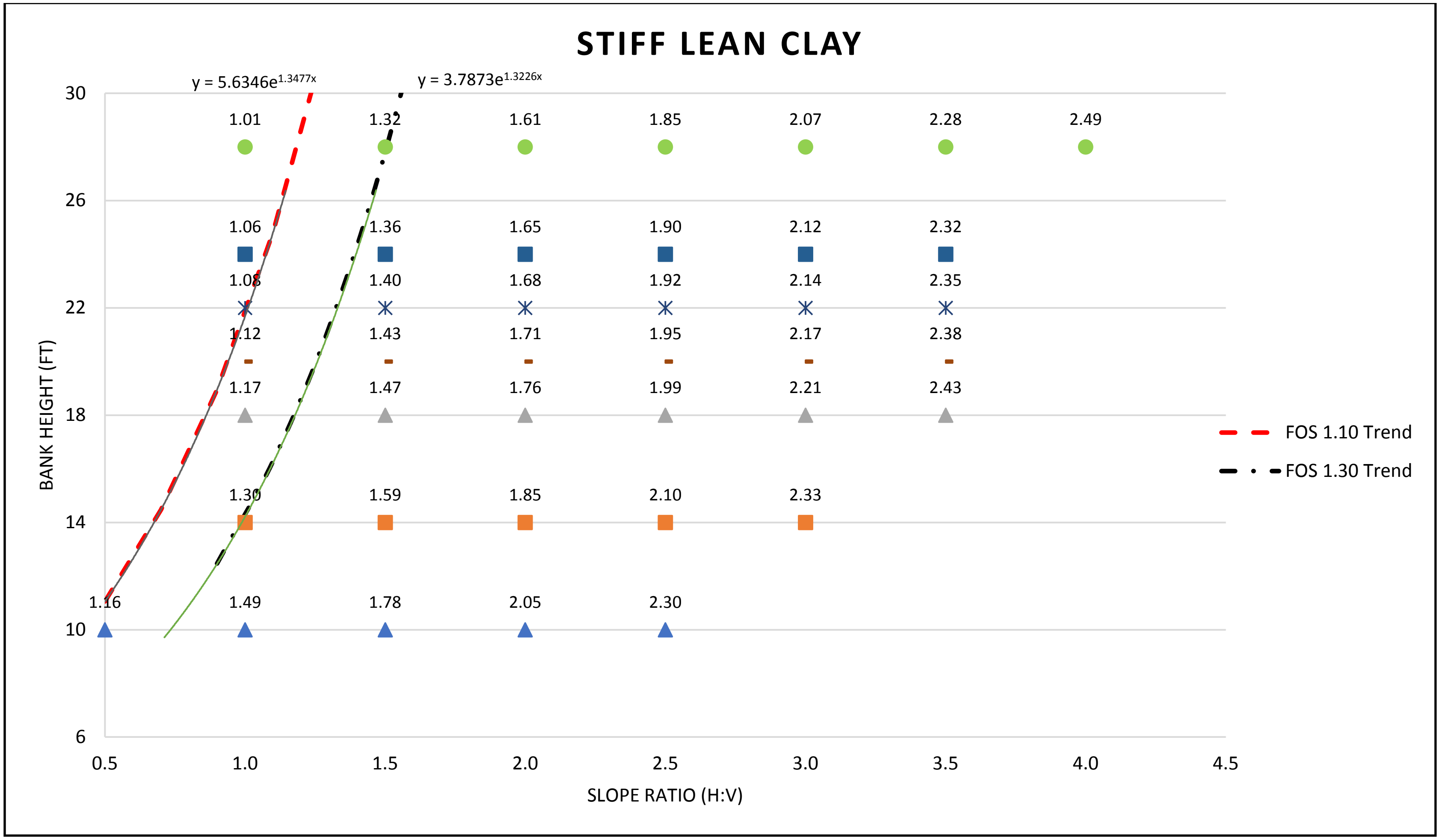
The graph features the soft fat clay (CH) material. The drained strength parameters for the soft CH are a friction angle of 22.0° and a cohesion of 100 pounds per square foot (psf). Undrained strength parameters for the material are a friction angle of 0° and cohesion of 500 psf.



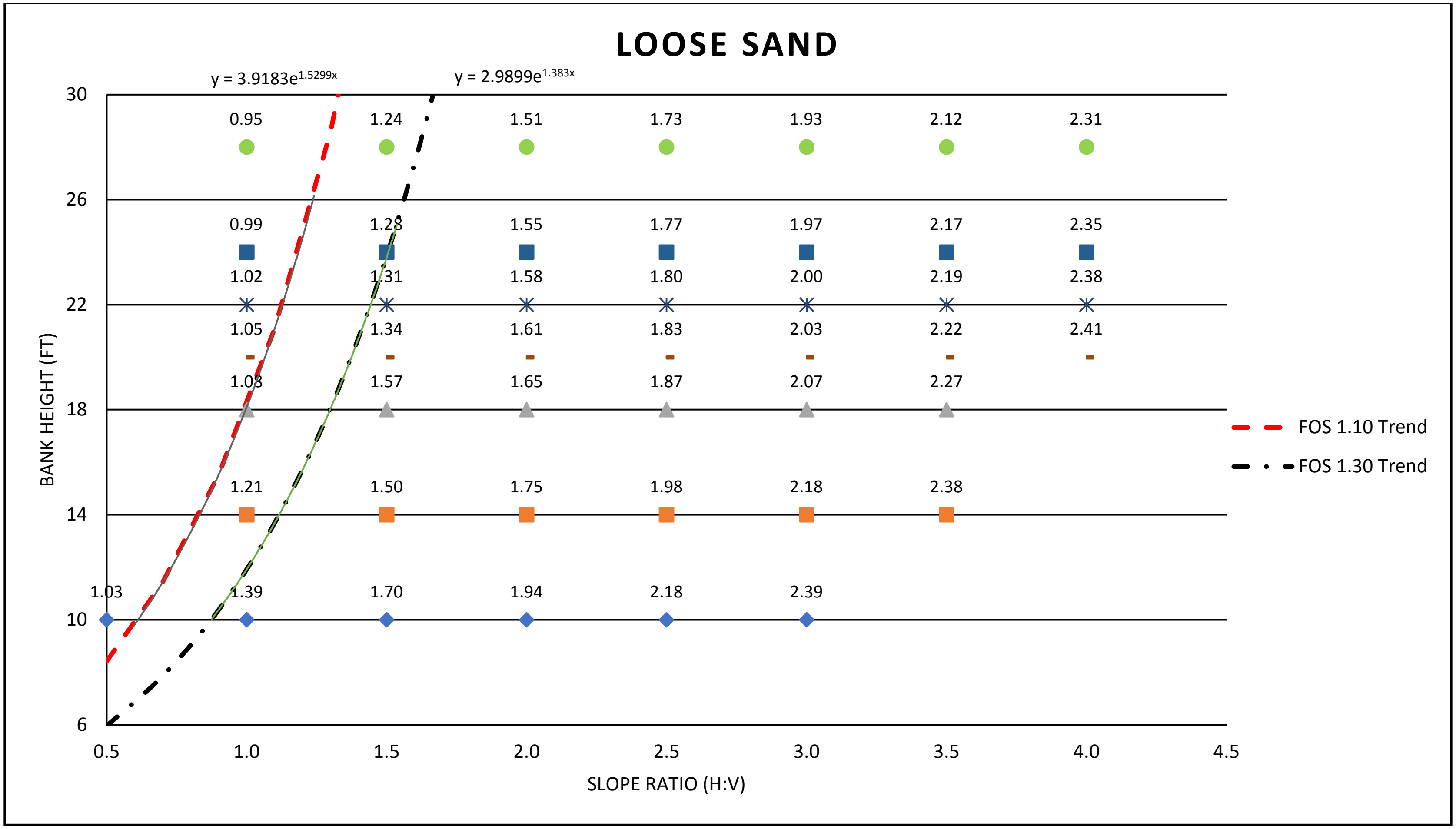
The graph features the stiff CH material. The drained strength parameters for the stiff CH are a friction angle of 26.0° and a cohesion of 100 psf. Undrained strength parameters for the material is a friction angle of 0° and cohesion of 2,000 psf.



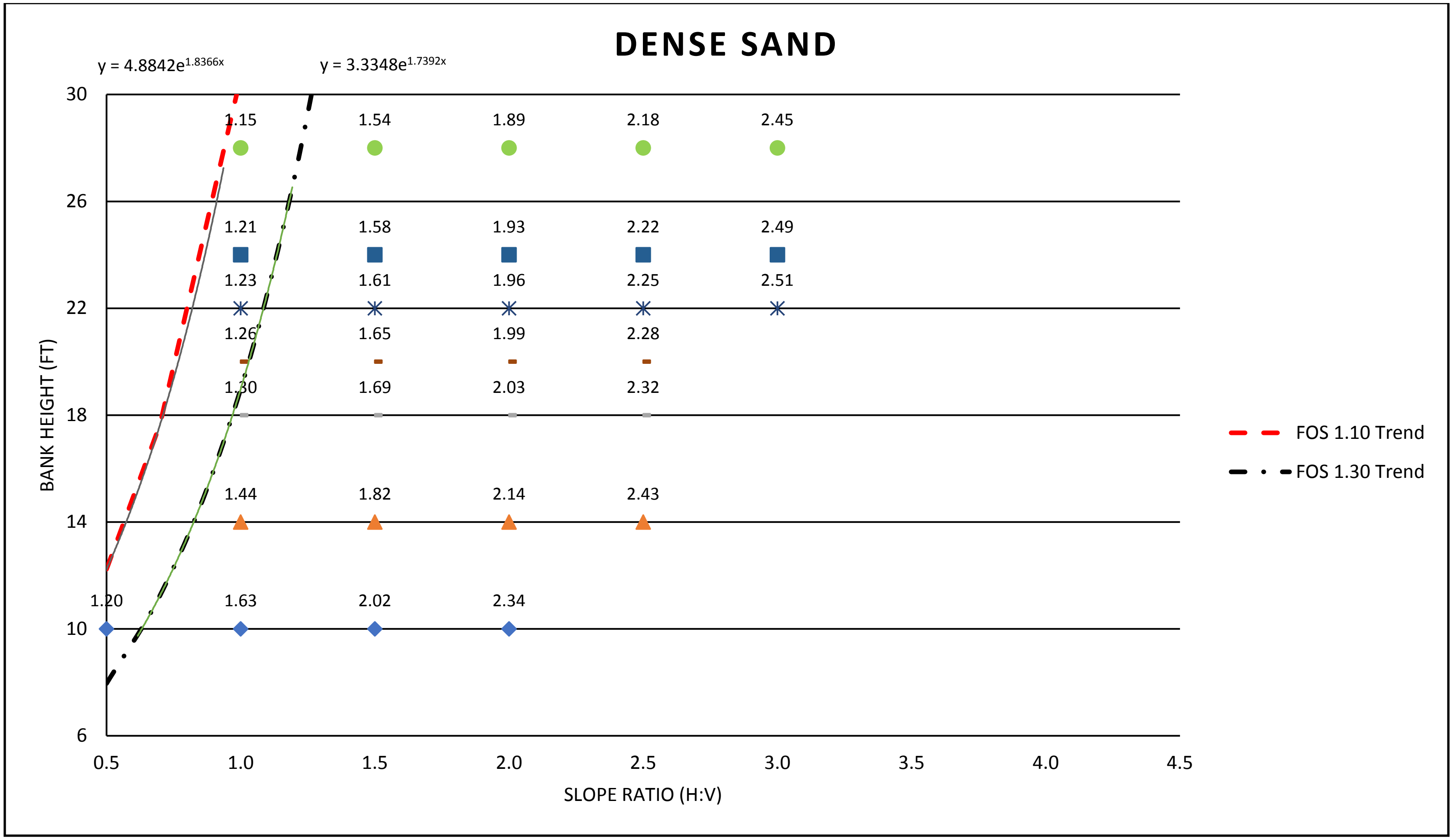
The graph features the soft lean clay (CL) material. The drained strength parameters for the soft CL are a friction angle of 24.0° and a cohesion of 100 psf. Undrained strength parameters for the material is a friction angle of 0° and cohesion of 500 psf.



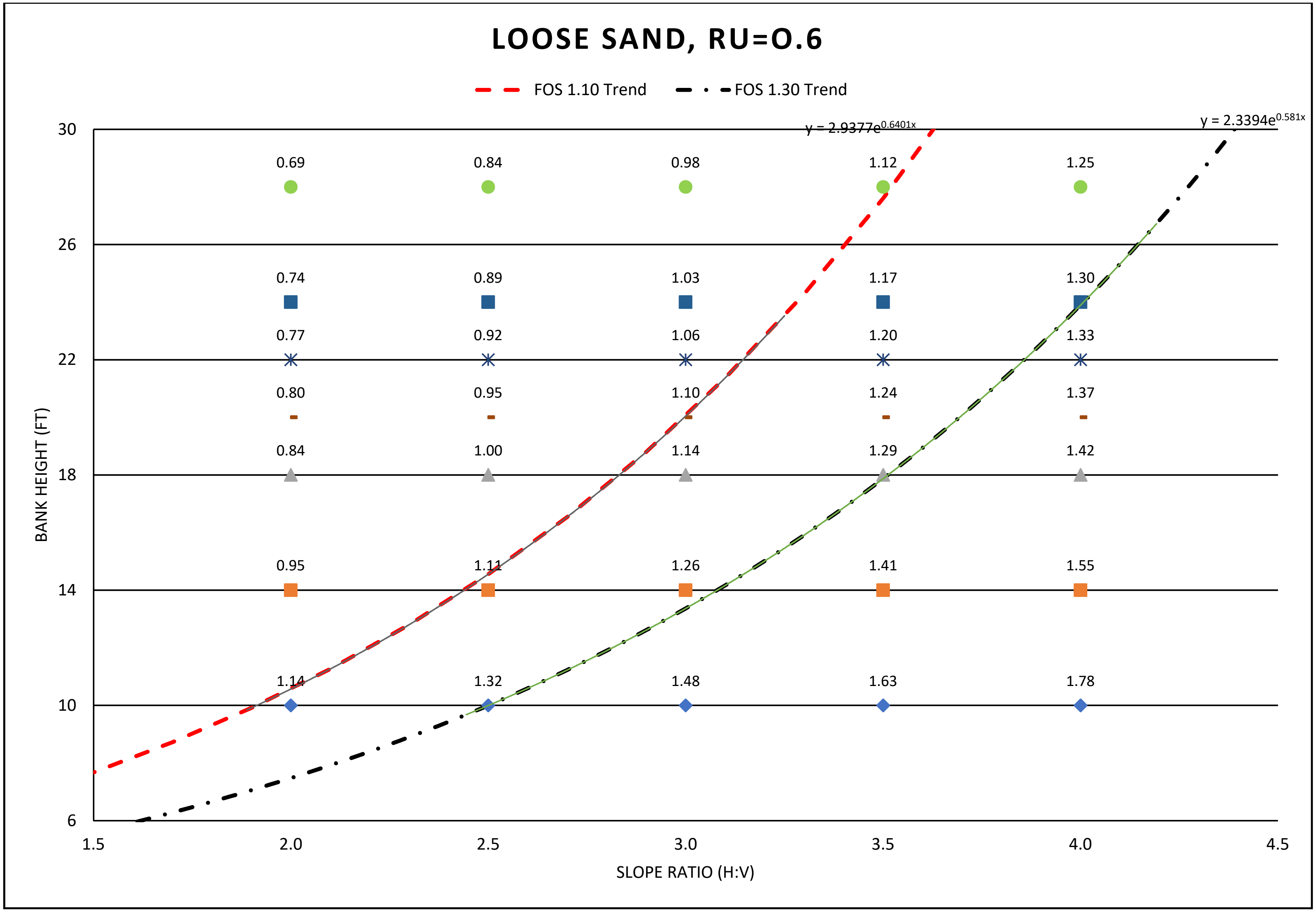
The graph features the stiff CL material. The drained strength parameters for the stiff CL are a friction angle of 30.0° and a cohesion of 100 psf. Undrained strength parameters for the material is a friction angle of 0° and cohesion of 2,000 psf.

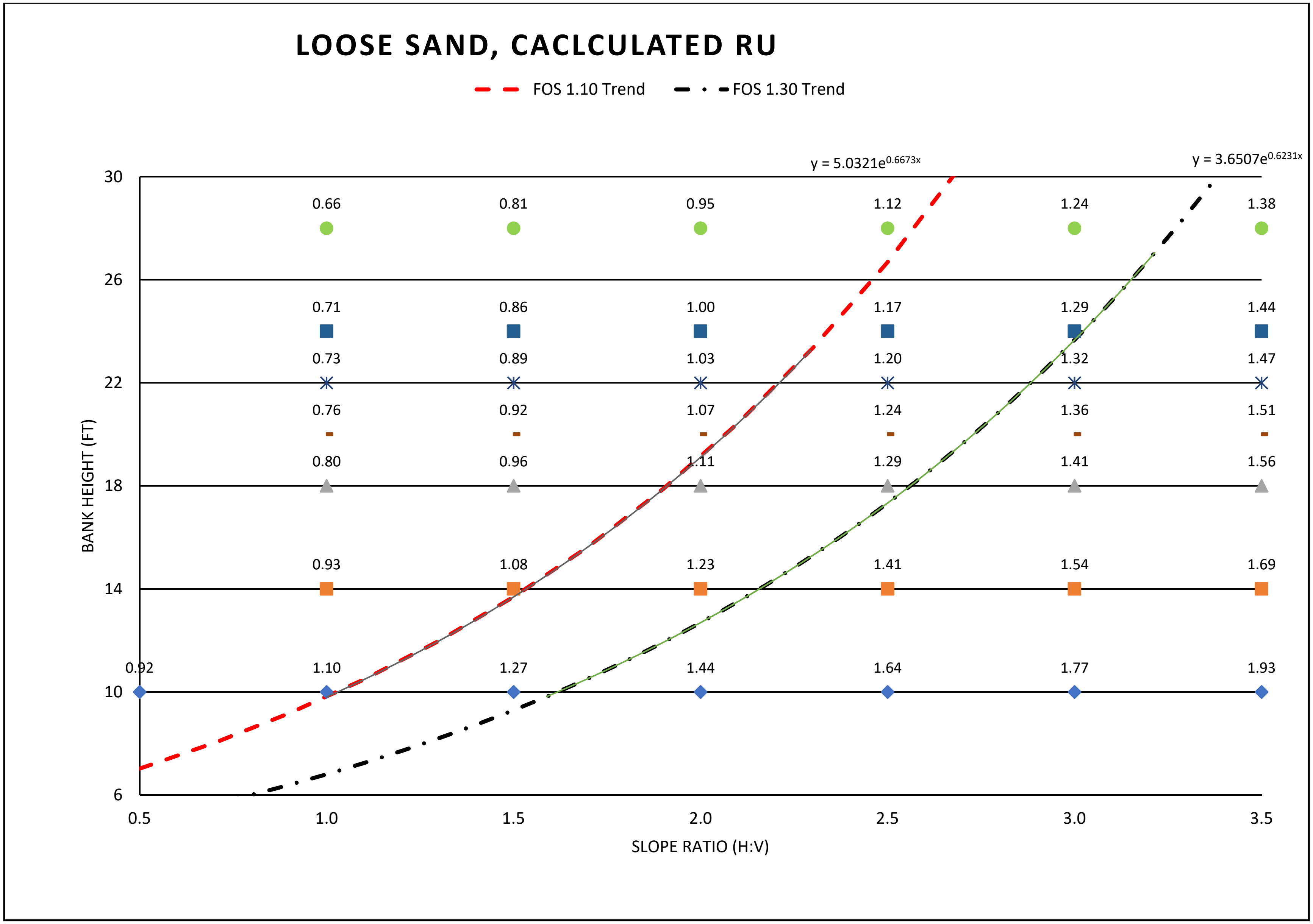


The graph features the loose silty/ clayey sand (SM-SC) material. The drained strength parameters for the loose SM-SC are a friction angle of 28.0° and a cohesion of 100 psf.



The graph features the dense SM-SC material. The drained strength parameters for the dense SM-SC are a friction angle of 35.0° and a cohesion of 100 psf.

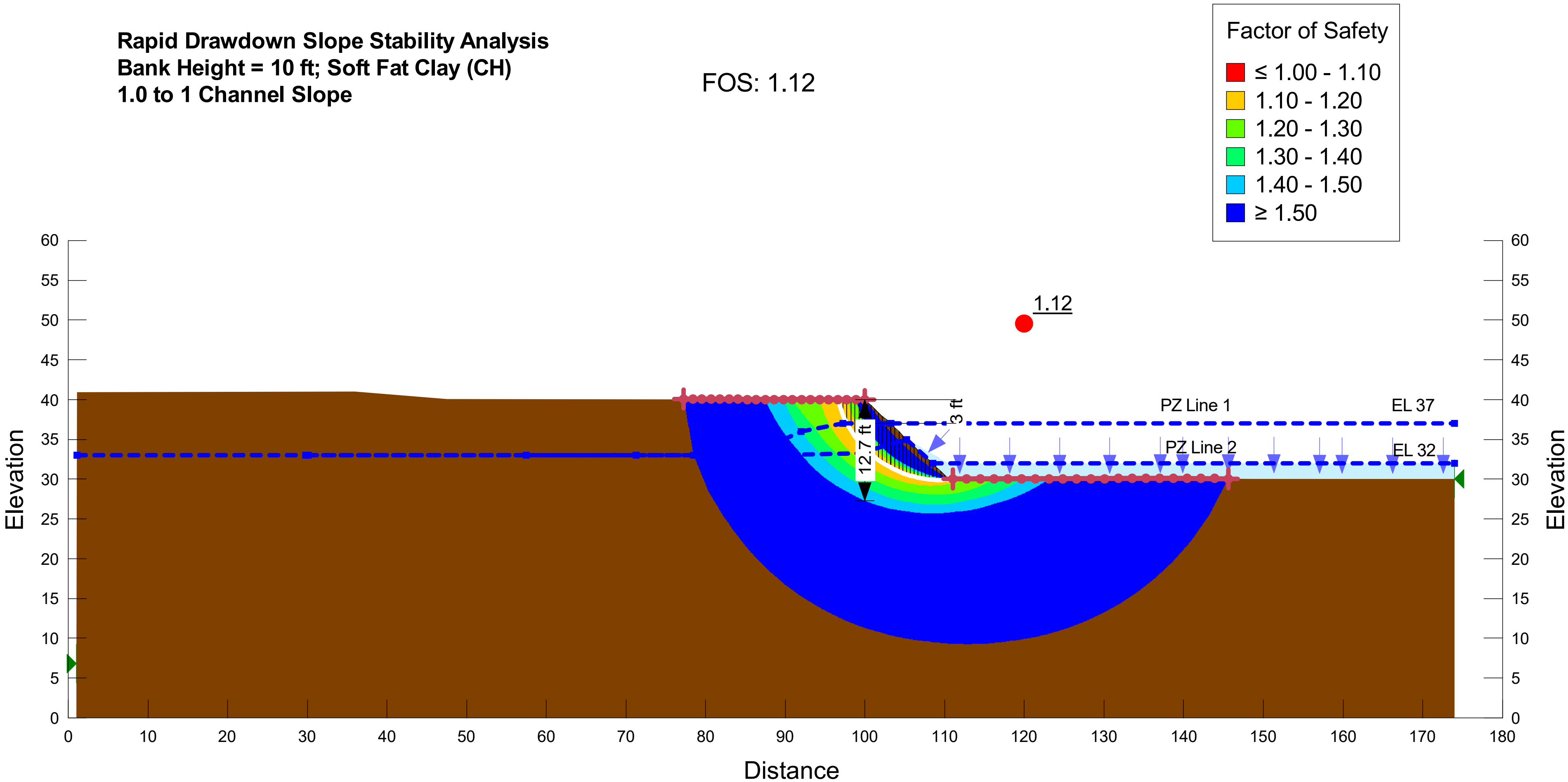

LOOSE SAND, RU=0.6
FOS 1.10 Trend
FOS 1.30 Trend
y = 2.9377e^0.6401x
y = 2.3394e^0.581x
0.69
0.84
0.98
1.12
1.25
0.74
0.89
1.03
1.17
1.30
0.77
0.92
1.06
1.20
1.33
0.80
0.95
1.10
1.24
1.37
0.84
1.00
1.14
1.29
1.42
0.95
1.11
1.26
1.41
1.55
1.14
1.32
1.48
1.63
1.78
BANK HEIGHT (FT)
30
26
22
18
14
10
6
1.5
2.0
2.5
3.0
3.5
4.0
4.5
SLOPE RATIO (H:V)



LOOSE SAND, CACLCULATED RU
FOS 1.10 Trend
FOS 1.30 Trend
y = 5.0321e^0.6673x
y = 3.6507e^0.6231x
0.66
0.81
0.95
1.12
1.24
1.38
0.71
0.86
1.00
1.17
1.29
1.44
0.73
0.89
1.03
1.20
1.32
1.47
0.76
0.92
1.07
1.24
1.36
1.51
0.80
0.96
1.11
1.29
1.41
1.56
0.93
1.08
1.23
1.41
1.54
1.69
0.92
1.10
1.27
1.44
1.64
1.77
1.93
BANK HEIGHT (FT)
30
26
22
18
14
10
6
0.5
1.0
1.5
2.0
2.5
3.0
3.5
SLOPE RATIO (H:V)

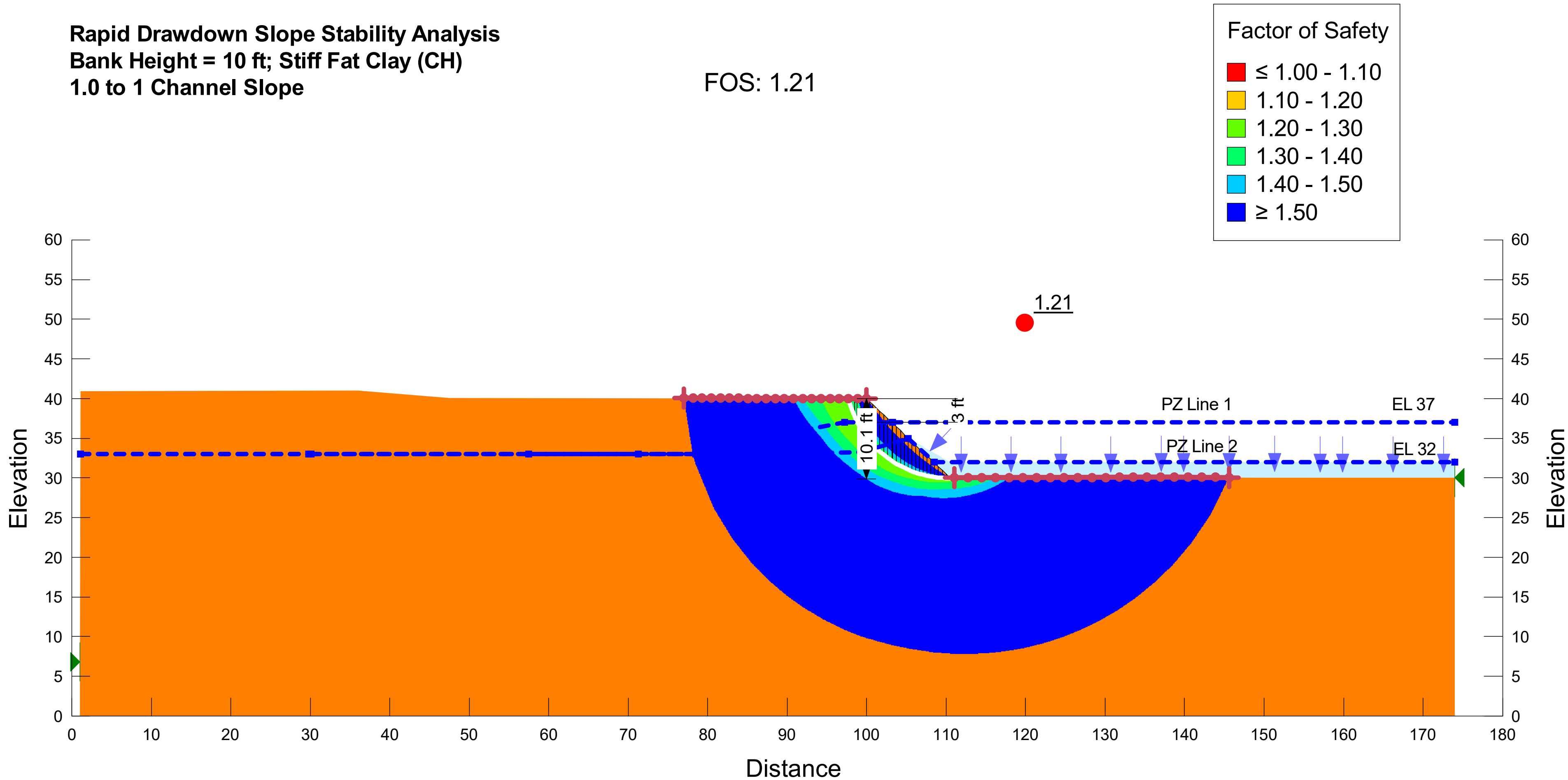
Rapid Drawdown Slope Stability Analysis
Bank Height = 10 ft; Soft Fat Clay (CH)
1.0 to 1 Channel Slope

FOS: 1.12



Color	Name	Unit Weight (pcf)	Effective Cohesion (psf)	Effective Friction Angle (°)	Cohesion R (psf)	Phi R (°)	Piezometric Surface	Piezometric Surface After Drawdown
	CH Soft	120	100	22	500	0	1	2

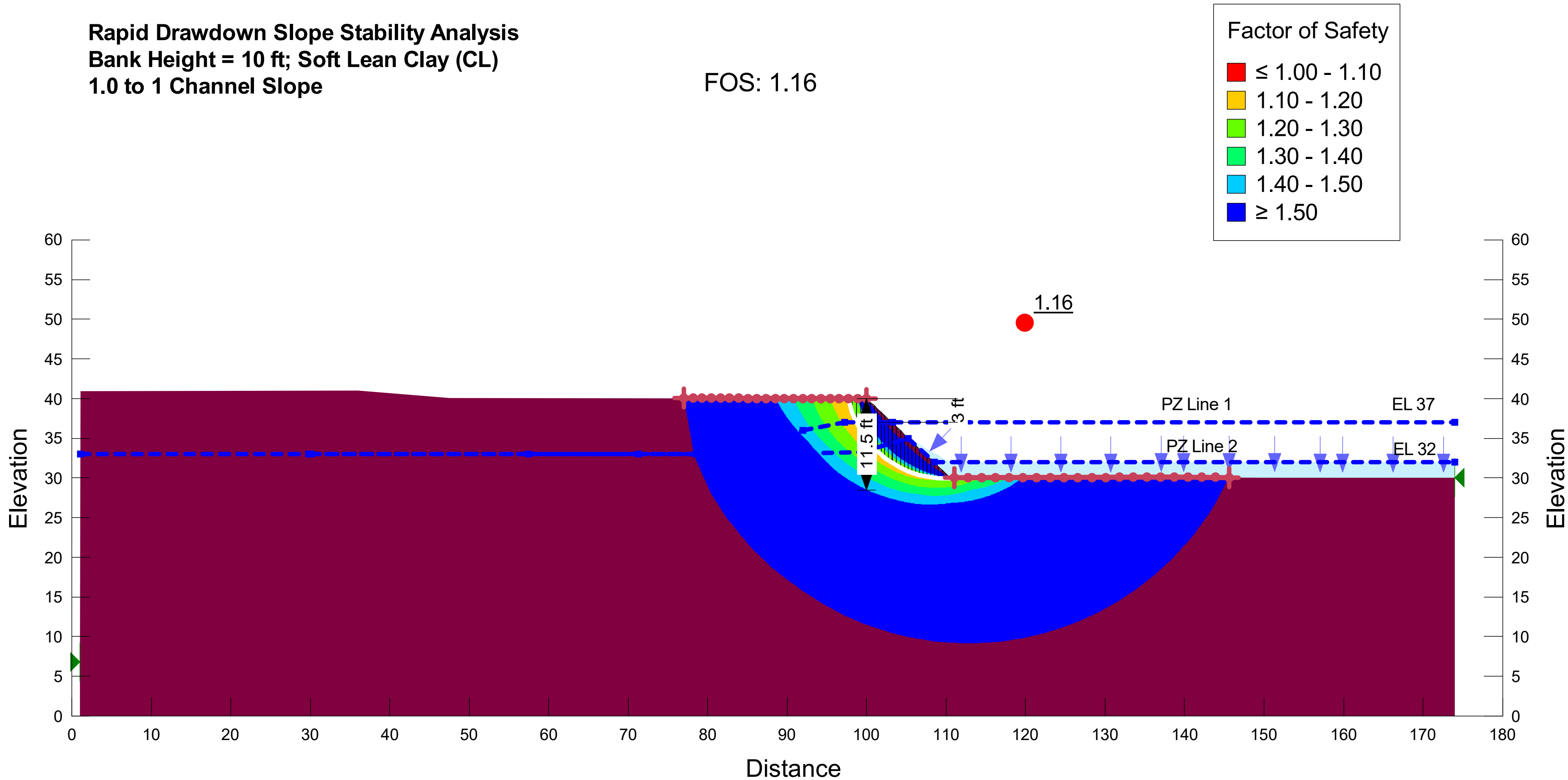
Rapid Drawdown Slope Stability Analysis
Bank Height = 10 ft; Stiff Fat Clay (CH)
1.0 to 1 Channel Slope



Color	Name	Unit Weight (pcf)	Effective Cohesion (psf)	Effective Friction Angle (°)	Cohesion R (psf)	Phi R (°)	Piezometric Surface	Piezometric Surface After Drawdown
	CH Stiff	120	100	26	2,000	0	1	2

Rapid Drawdown Slope Stability Analysis
Bank Height = 10 ft; Soft Lean Clay (CL)
1.0 to 1 Channel Slope

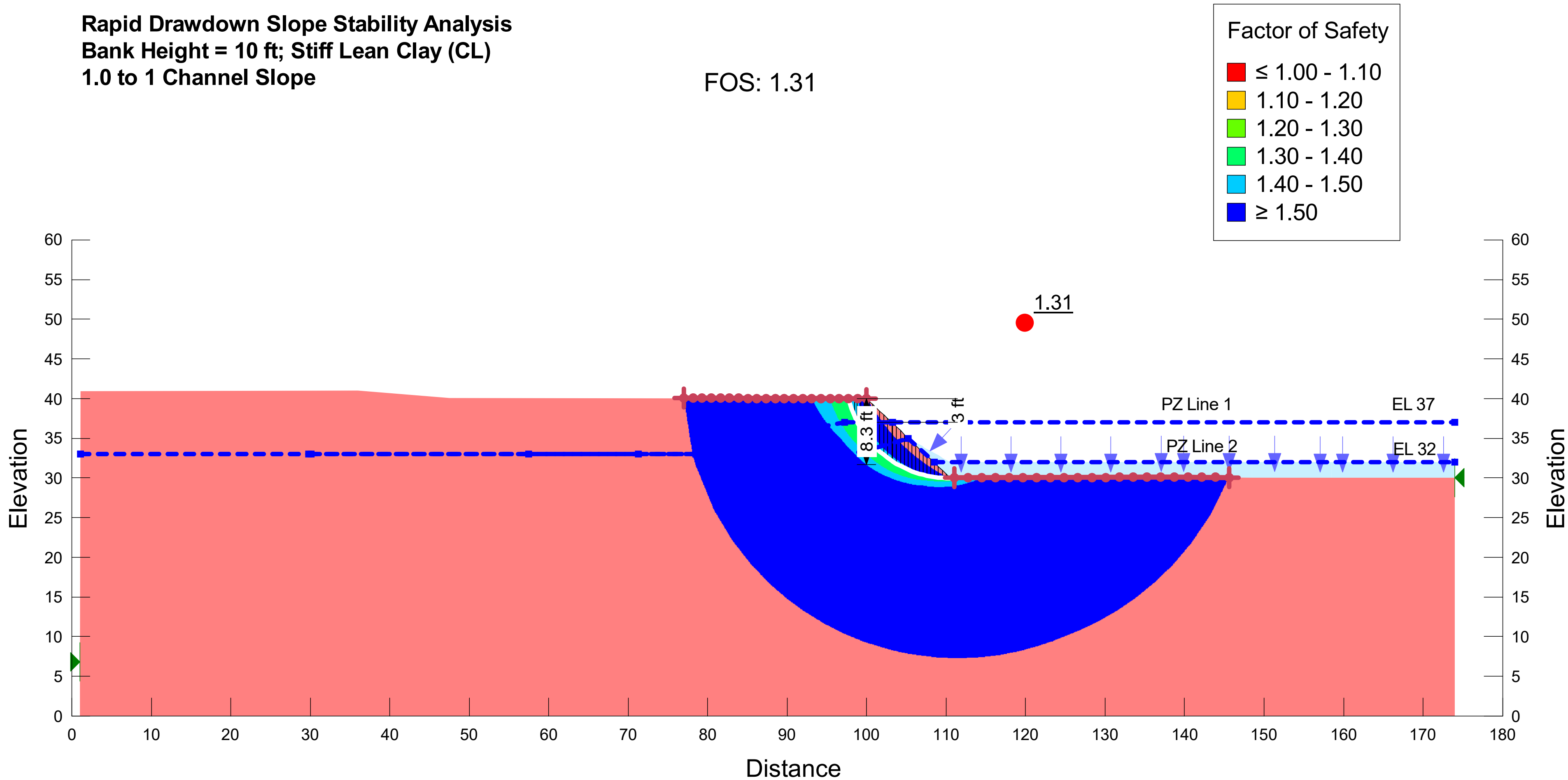
FOS: 1.16



Color	Name	Unit Weight (pcf)	Effective Cohesion (psf)	Effective Friction Angle (°)	Cohesion R (psf)	Phi R (°)	Piezometric Surface	Piezometric Surface After Drawdown
	CL Soft	120	100	24	500	0	1	2

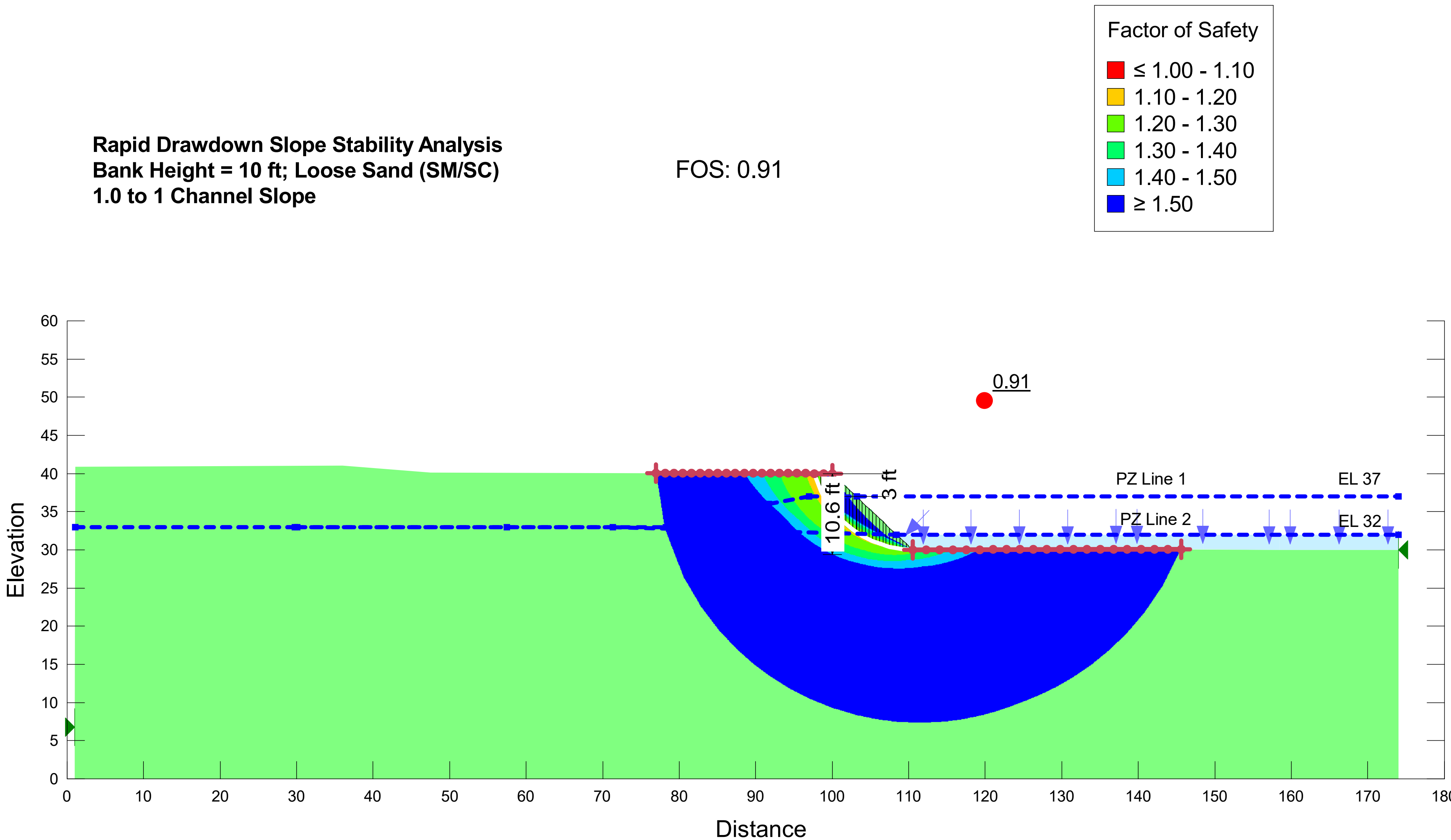
Rapid Drawdown Slope Stability Analysis
Bank Height = 10 ft; Stiff Lean Clay (CL)
1.0 to 1 Channel Slope

FOS: 1.31



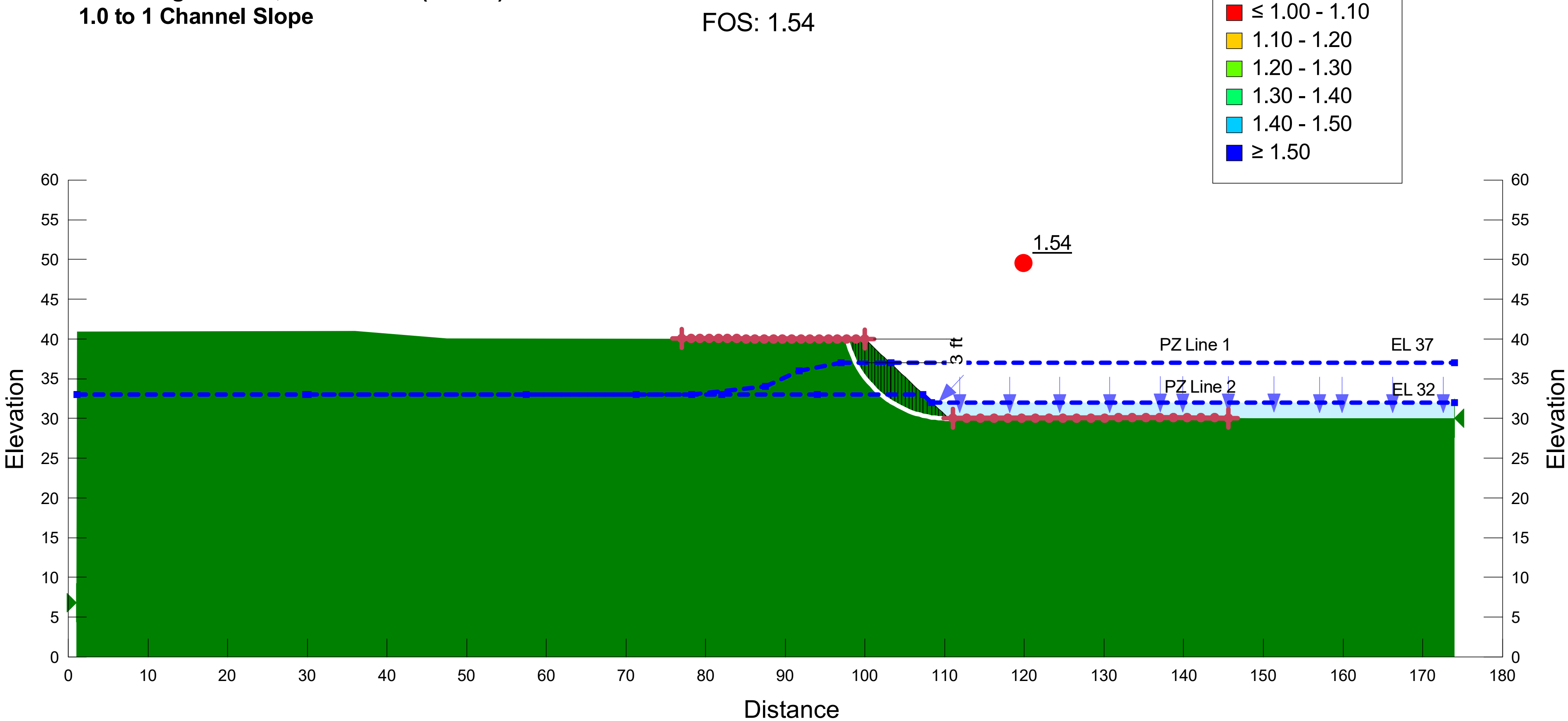
Color	Name	Unit Weight (pcf)	Effective Cohesion (psf)	Effective Friction Angle (°)	Cohesion R (psf)	Phi R (°)	Piezometric Surface	Piezometric Surface After Drawdown
	CL Stiff	120	100	30	2,000	0	1	2

Rapid Drawdown Slope Stability Analysis
Bank Height = 10 ft; Loose Sand (SM/SC)
1.0 to 1 Channel Slope



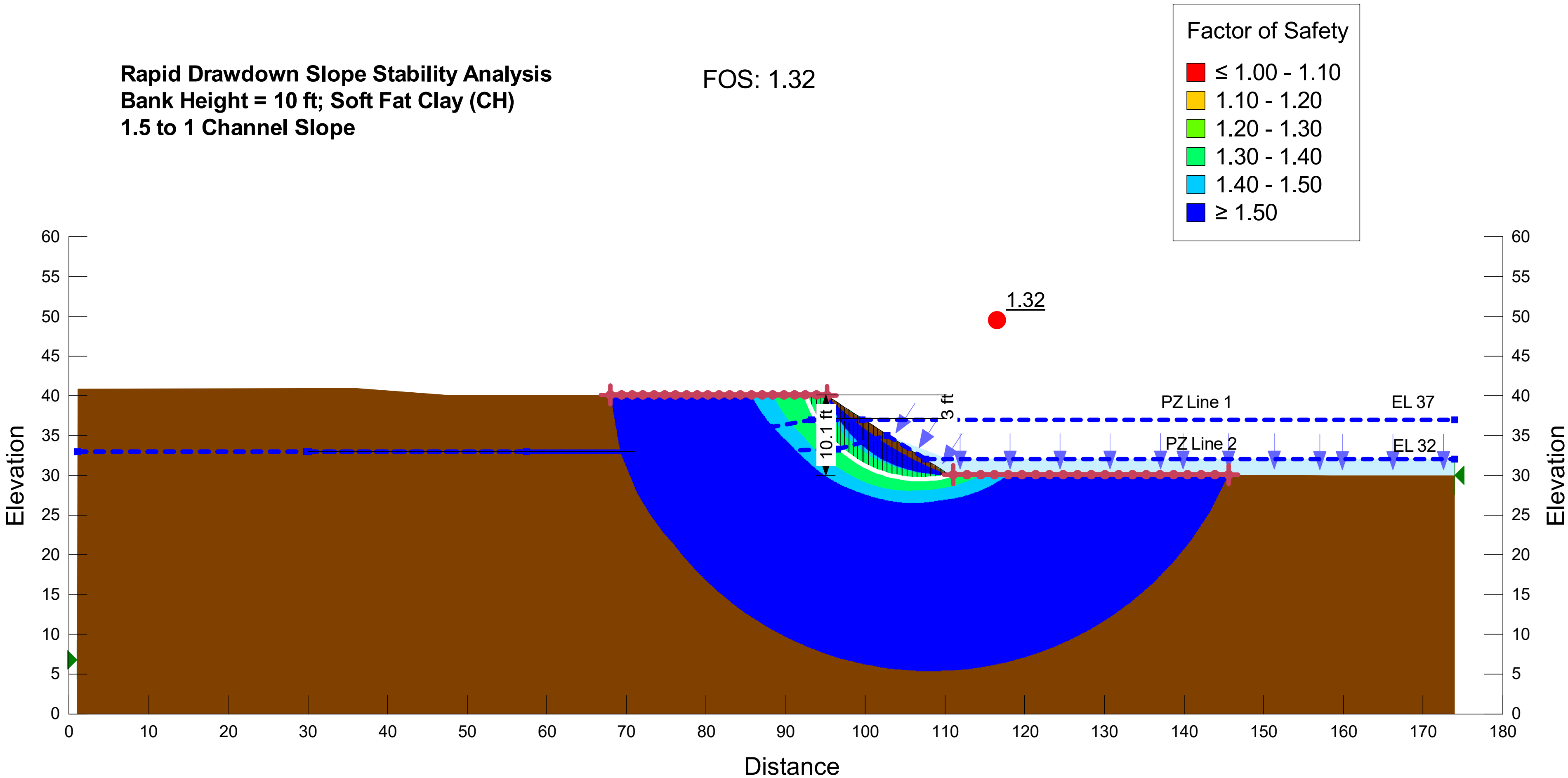
Color	Name	Unit Weight (pcf)	Effective Cohesion (psf)	Effective Friction Angle (°)	Cohesion R (psf)	Phi R (°)	Piezometric Surface	Piezometric Surface After Drawdown
	SM/SC Loose	120	100	28	110	20	1	2

Rapid Drawdown Slope Stability Analysis
Bank Height = 10 ft; Dense Sand (SM/SC)
1.0 to 1 Channel Slope



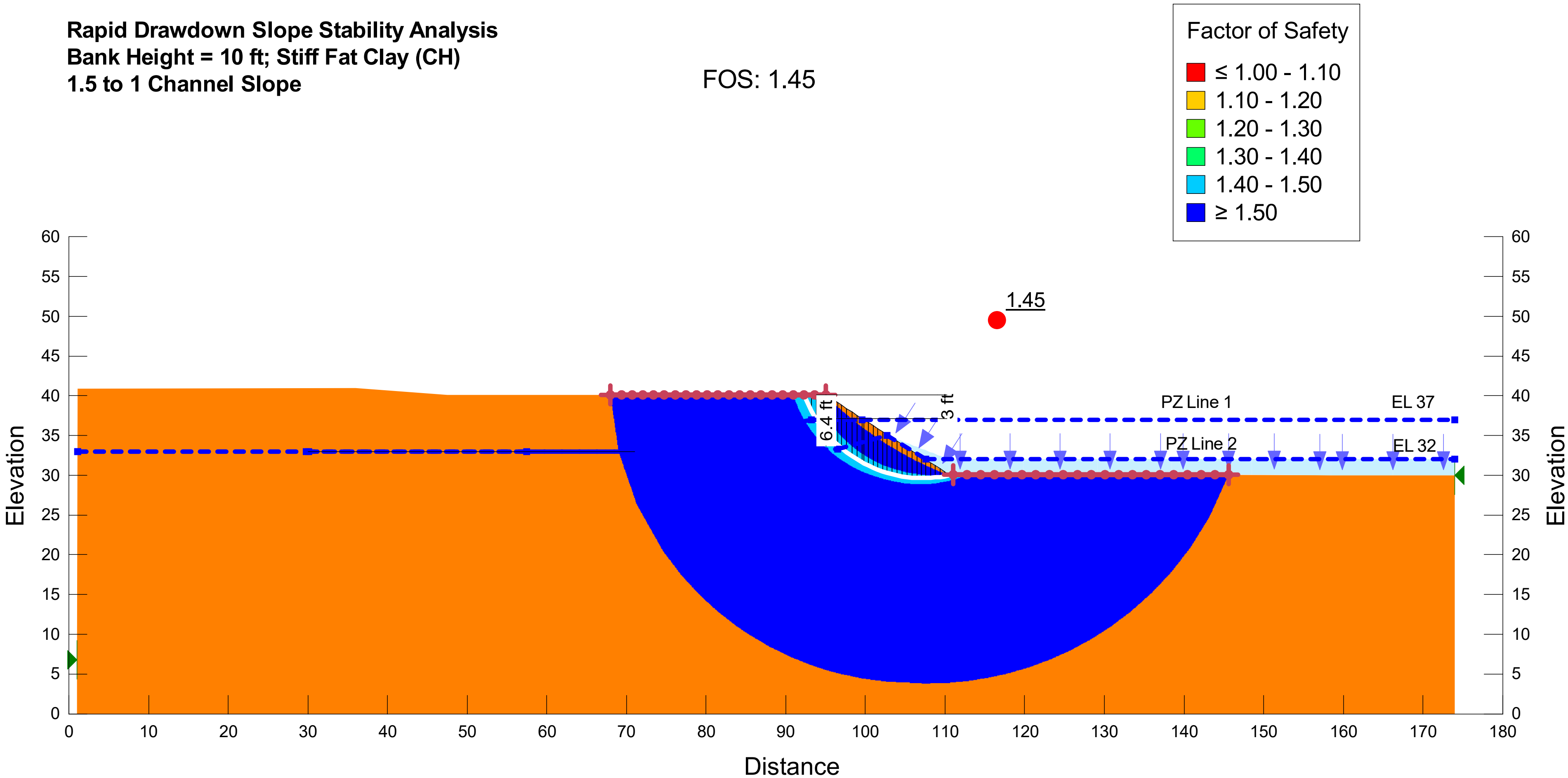
Color	Name	Unit Weight (pcf)	Effective Cohesion (psf)	Effective Friction Angle (°)	Cohesion R (psf)	Phi R (°)	Piezometric Surface	Piezometric Surface After Drawdown
	SM/SC Dense	120	100	35	150	27	1	2

Rapid Drawdown Slope Stability Analysis
Bank Height = 10 ft; Soft Fat Clay (CH)
1.5 to 1 Channel Slope



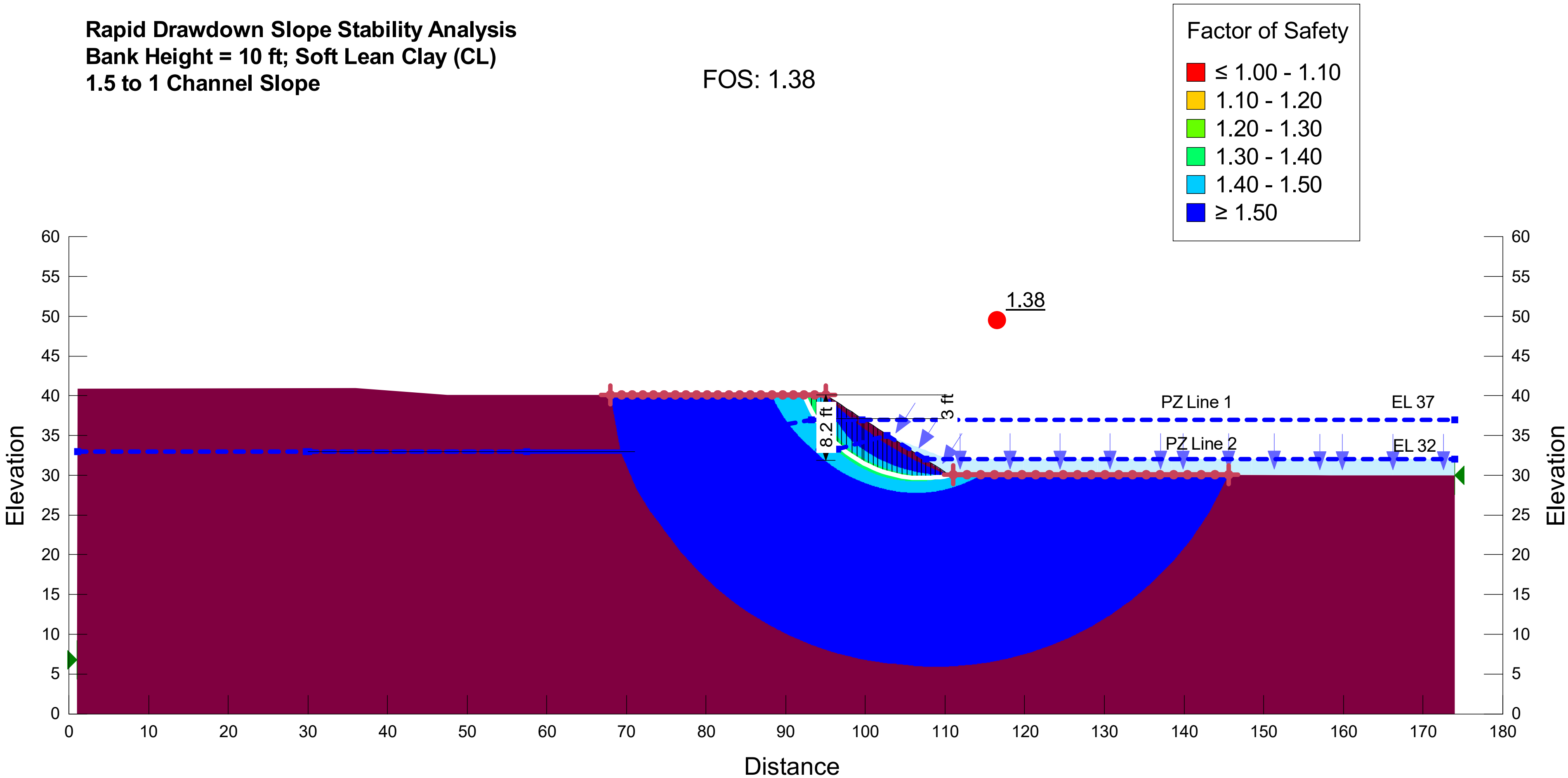
Color	Name	Unit Weight (pcf)	Effective Cohesion (psf)	Effective Friction Angle (°)	Cohesion R (psf)	Phi R (°)	Piezometric Surface	Piezometric Surface After Drawdown
	CH Soft	120	100	22	500	0	1	2

Rapid Drawdown Slope Stability Analysis
Bank Height = 10 ft; Stiff Fat Clay (CH)
1.5 to 1 Channel Slope



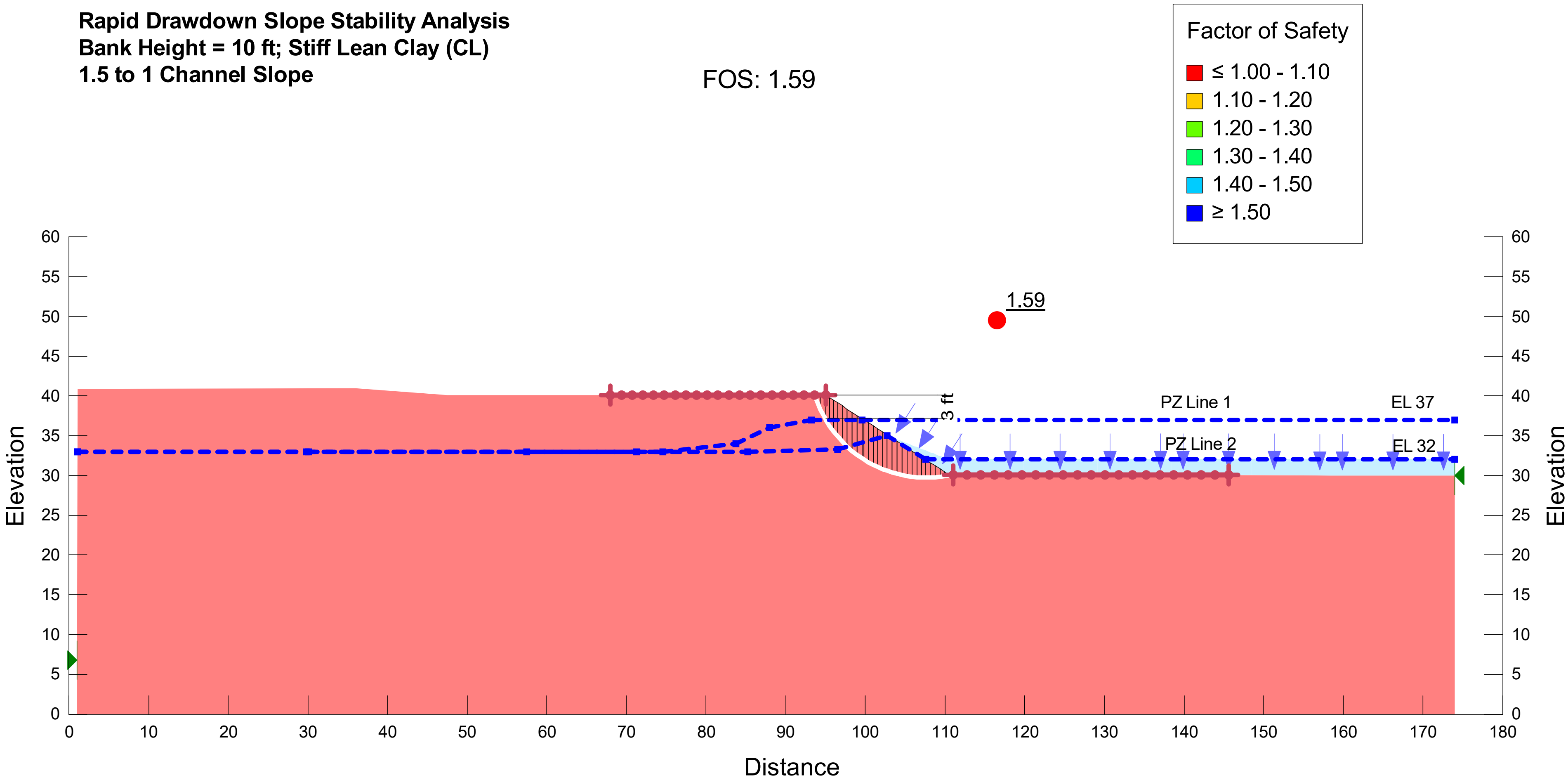
Color	Name	Unit Weight (pcf)	Effective Cohesion (psf)	Effective Friction Angle (°)	Cohesion R (psf)	Phi R (°)	Piezometric Surface	Piezometric Surface After Drawdown
	CH Stiff	120	100	26	2,000	0	1	2

Rapid Drawdown Slope Stability Analysis
Bank Height = 10 ft; Soft Lean Clay (CL)
1.5 to 1 Channel Slope



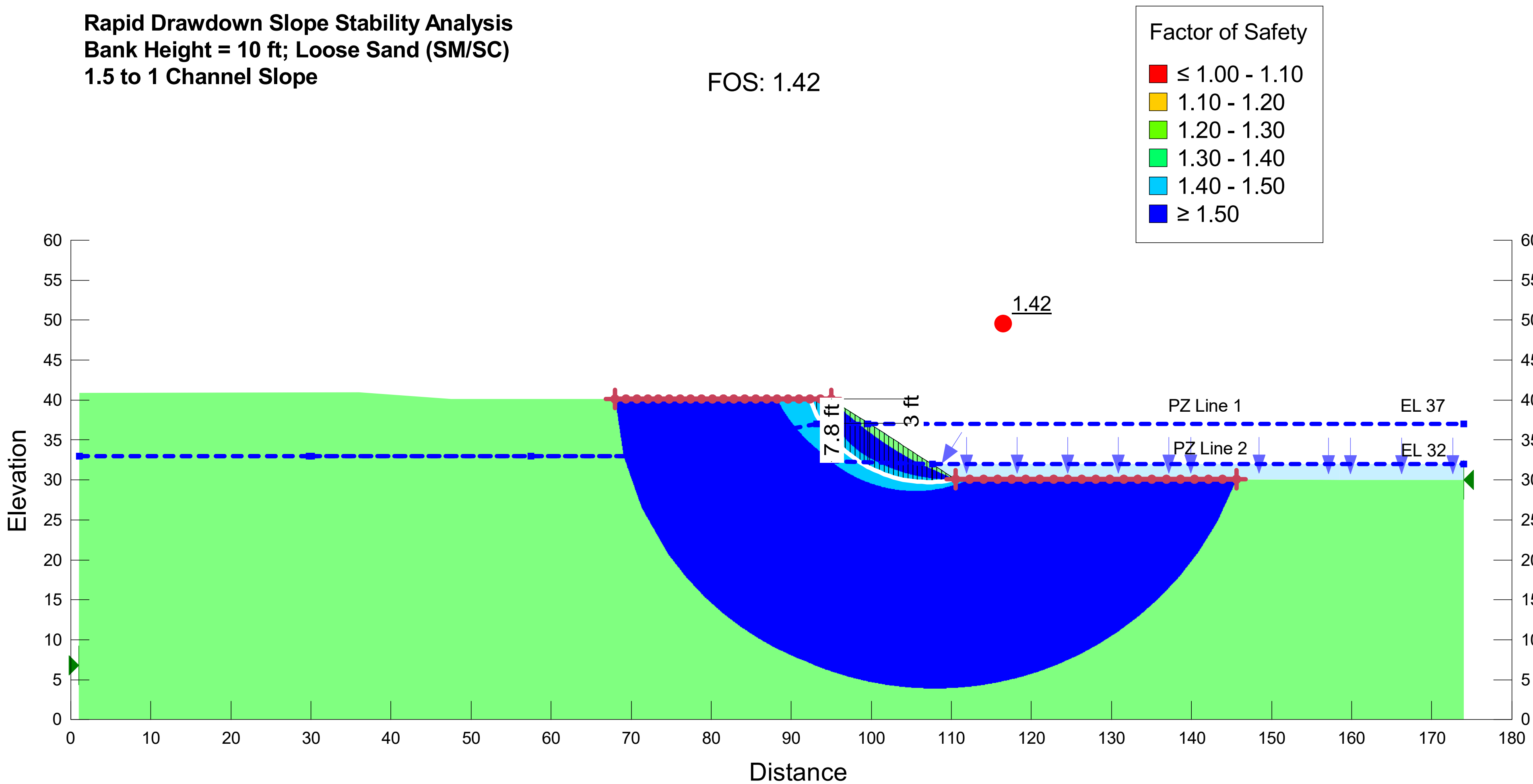
Color	Name	Unit Weight (pcf)	Effective Cohesion (psf)	Effective Friction Angle (°)	Cohesion R (psf)	Phi R (°)	Piezometric Surface	Piezometric Surface After Drawdown
	CL Soft	120	100	24	500	0	1	2

Rapid Drawdown Slope Stability Analysis
Bank Height = 10 ft; Stiff Lean Clay (CL)
1.5 to 1 Channel Slope

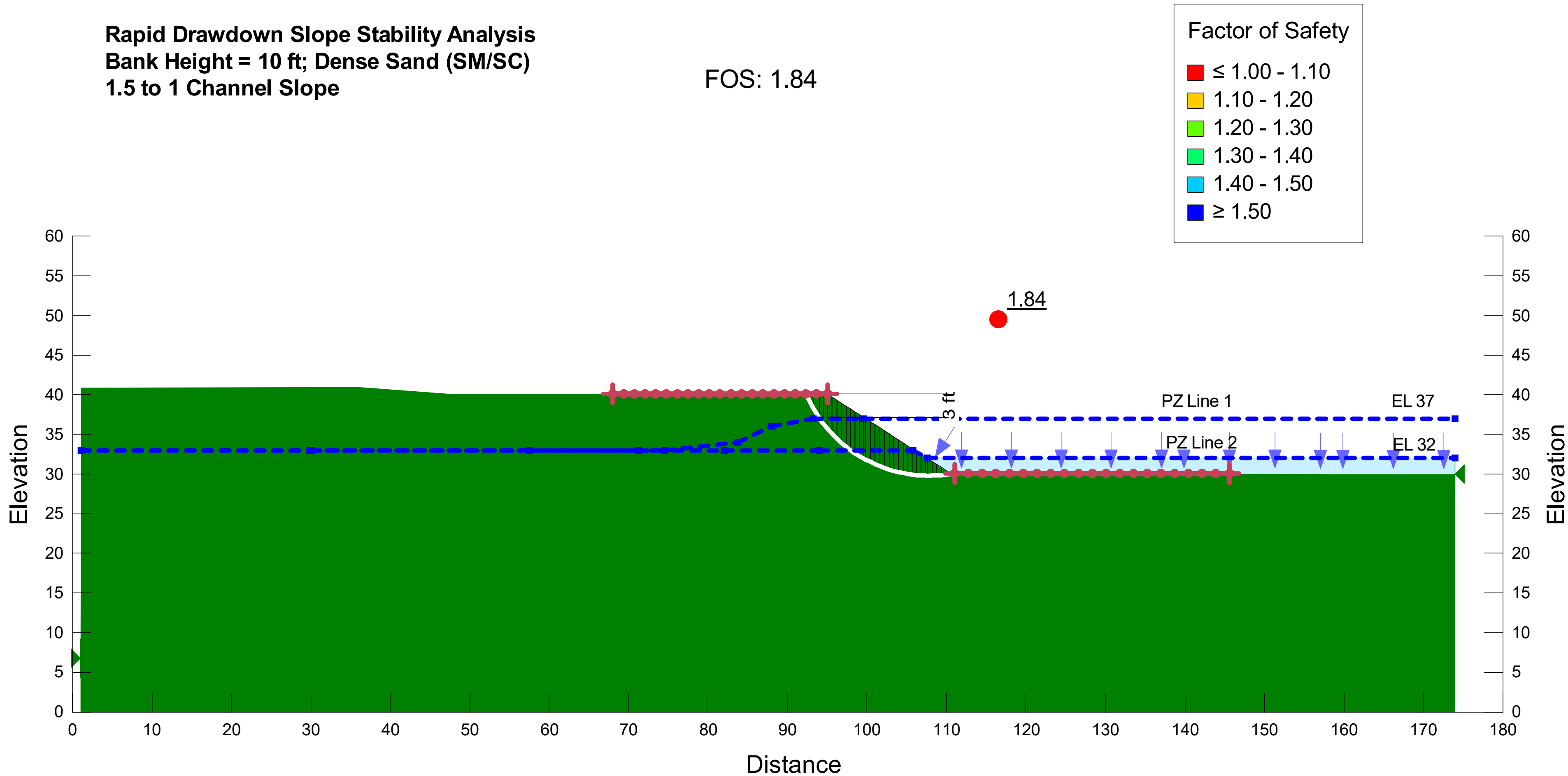


Color	Name	Unit Weight (pcf)	Effective Cohesion (psf)	Effective Friction Angle (°)	Cohesion R (psf)	Phi R (°)	Piezometric Surface	Piezometric Surface After Drawdown
	CL Stiff	120	100	30	2,000	0	1	2

Rapid Drawdown Slope Stability Analysis
Bank Height = 10 ft; Loose Sand (SM/SC)
1.5 to 1 Channel Slope



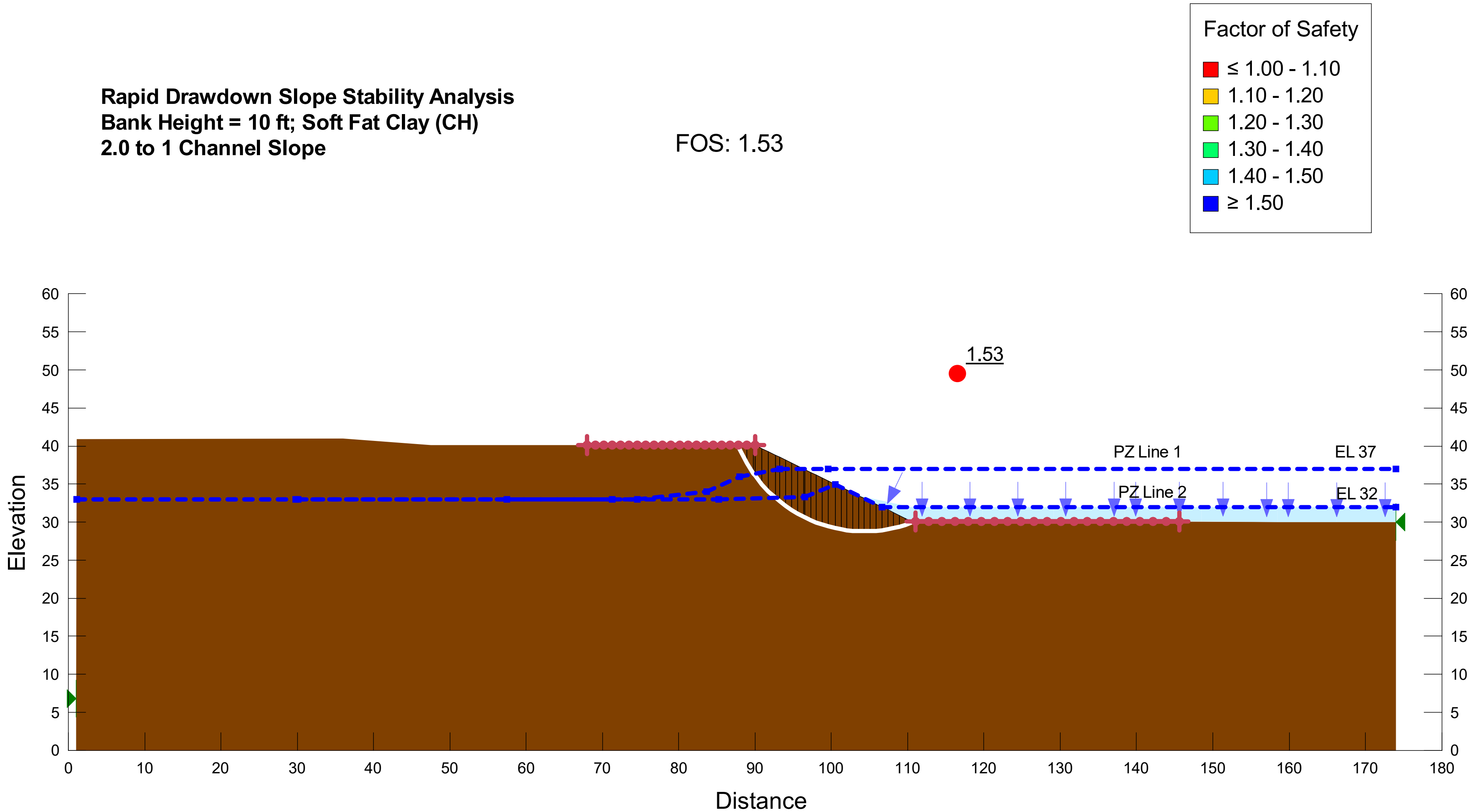
Color	Name	Unit Weight (pcf)	Effective Cohesion (psf)	Effective Friction Angle (°)	Cohesion R (psf)	Phi R (°)	Piezometric Surface	Piezometric Surface After Drawdown
	SM/SC Loose	120	100	28	110	20	1	2



Color	Name	Unit Weight (pcf)	Effective Cohesion (psf)	Effective Friction Angle (°)	Cohesion R (psf)	Phi R (°)	Piezometric Surface	Piezometric Surface After Drawdown
	SM/SC Dense	120	100	35	150	27	1	2

Rapid Drawdown Slope Stability Analysis
Bank Height = 10 ft; Soft Fat Clay (CH)
2.0 to 1 Channel Slope

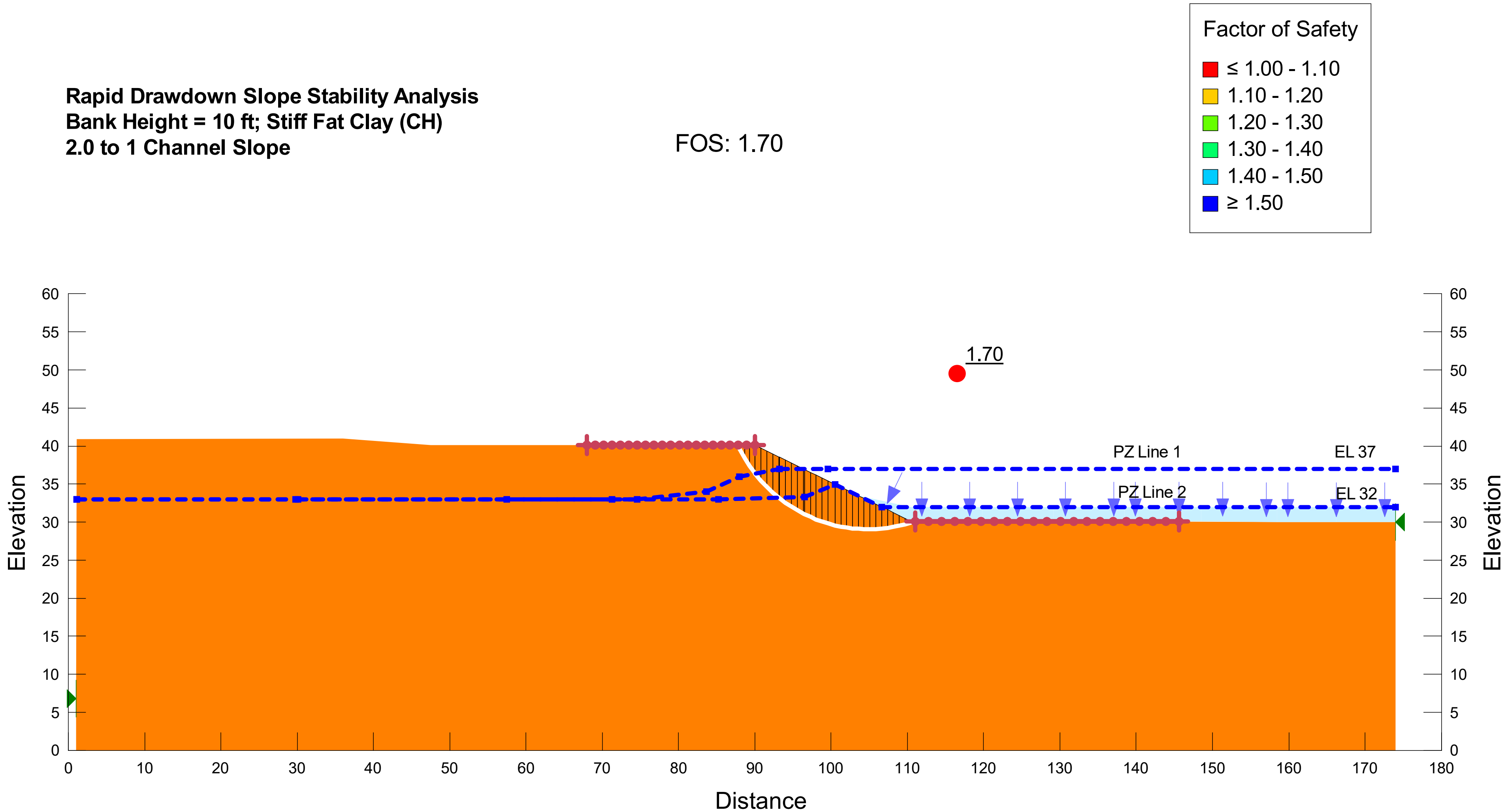
FOS: 1.53



Color	Name	Unit Weight (pcf)	Effective Cohesion (psf)	Effective Friction Angle (°)	Cohesion R (psf)	Phi R (°)	Piezometric Surface	Piezometric Surface After Drawdown
	CH Soft	120	100	22	500	0	1	2

Rapid Drawdown Slope Stability Analysis
Bank Height = 10 ft; Stiff Fat Clay (CH)
2.0 to 1 Channel Slope

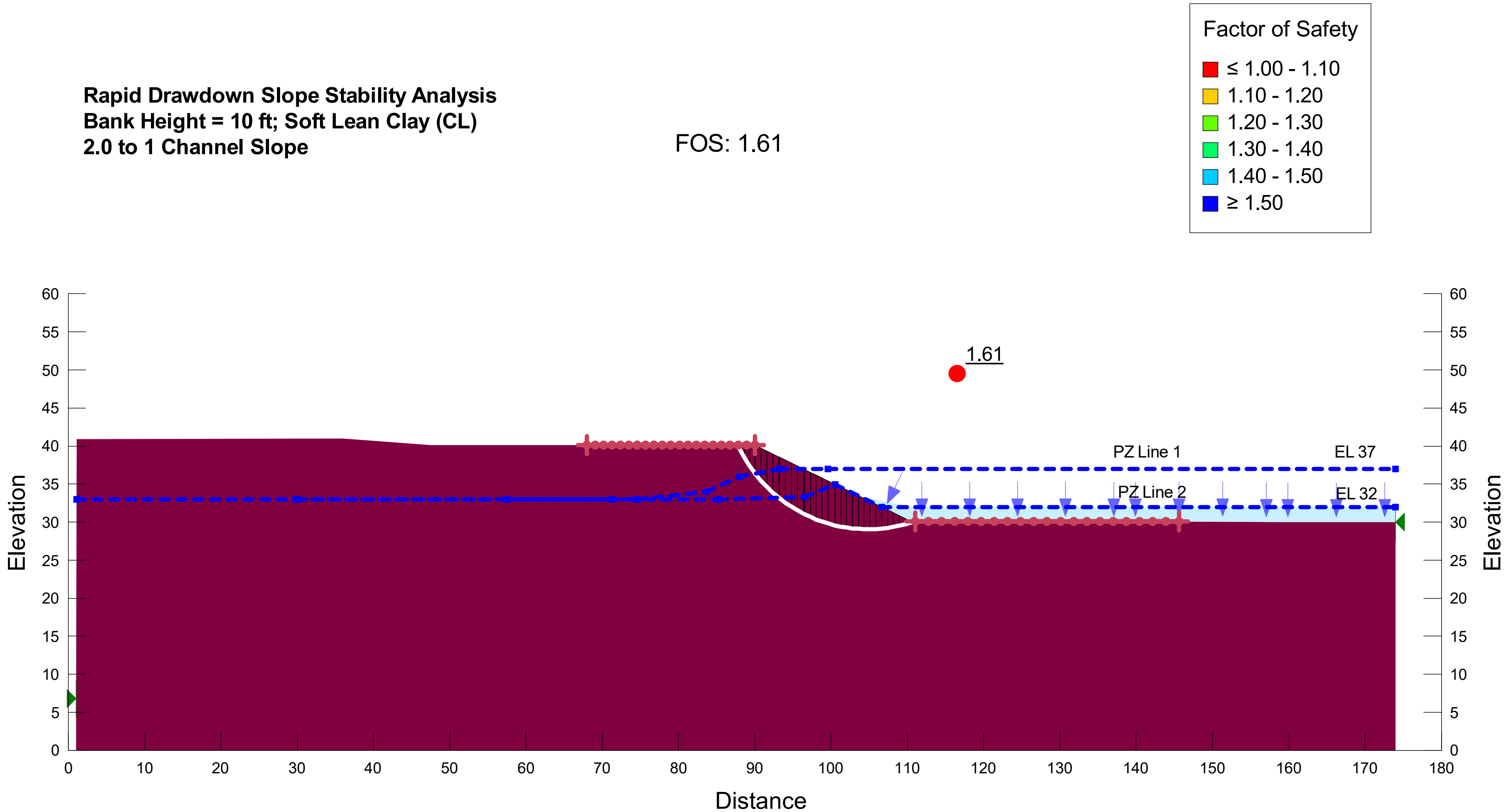
FOS: 1.70



Color	Name	Unit Weight (pcf)	Effective Cohesion (psf)	Effective Friction Angle (°)	Cohesion R (psf)	Phi R (°)	Piezometric Surface	Piezometric Surface After Drawdown
	CH Stiff	120	100	26	2,000	0	1	2

Rapid Drawdown Slope Stability Analysis
Bank Height = 10 ft; Soft Lean Clay (CL)
2.0 to 1 Channel Slope

FOS: 1.61

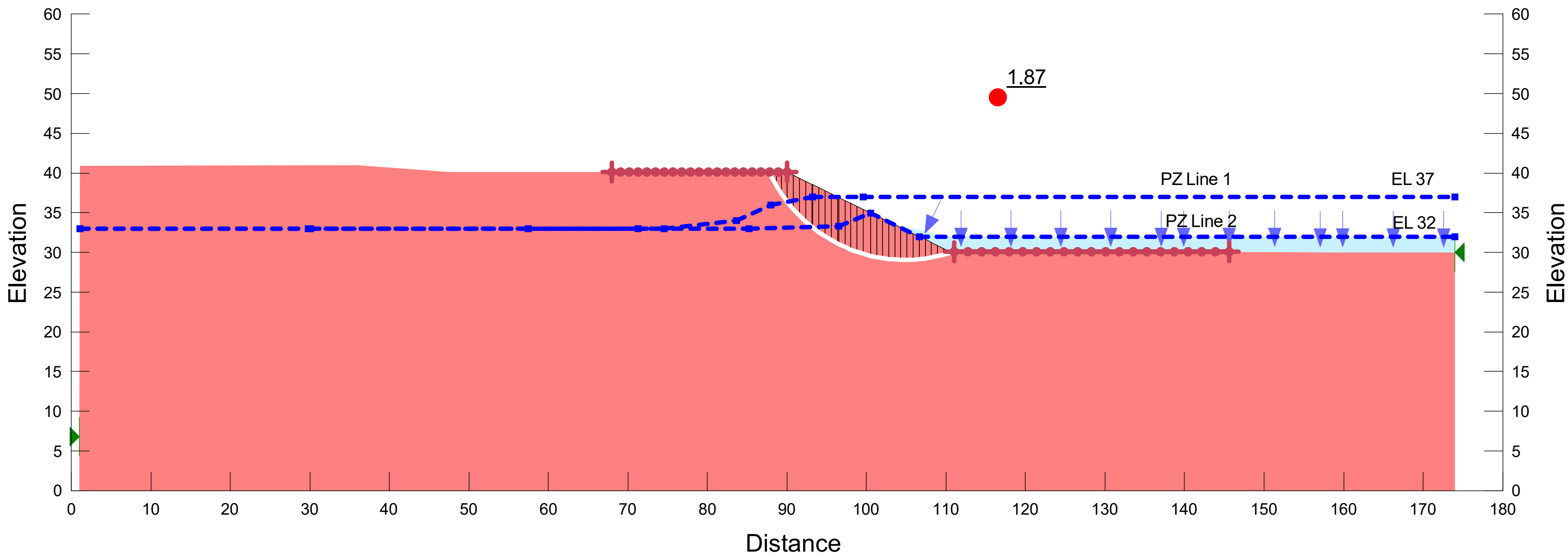


Color	Name	Unit Weight (pcf)	Effective Cohesion (psf)	Effective Friction Angle (°)	Cohesion R (psf)	Phi R (°)	Piezometric Surface	Piezometric Surface After Drawdown
	CL Soft	120	100	24	500	0	1	2

Rapid Drawdown Slope Stability Analysis
Bank Height = 10 ft; Stiff Lean Clay (CL)
2.0 to 1 Channel Slope

FOS: 1.87

Factor of Safety
- ≤ 1.00 - 1.10
- 1.10 - 1.20
- 1.20 - 1.30
- 1.30 - 1.40
- 1.40 - 1.50
- ≥ 1.50



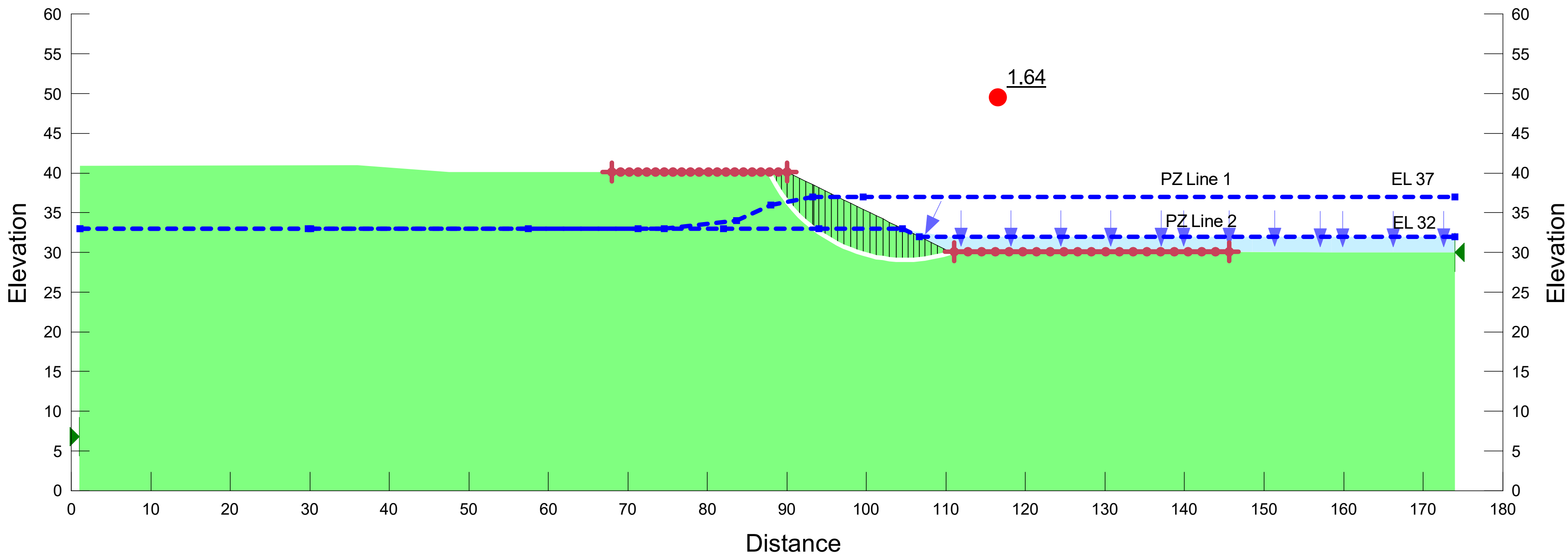
Color	Name	Unit Weight (pcf)	Effective Cohesion (psf)	Effective Friction Angle (°)	Cohesion R (psf)	Phi R (°)	Piezometric Surface	Piezometric Surface After Drawdown
	CL Stiff	120	100	30	2,000	0	1	2

Rapid Drawdown Slope Stability Analysis
Bank Height = 10 ft; Loose Sand (SM/SC)
2.0 to 1 Channel Slope

FOS: 1.64

Factor of Safety

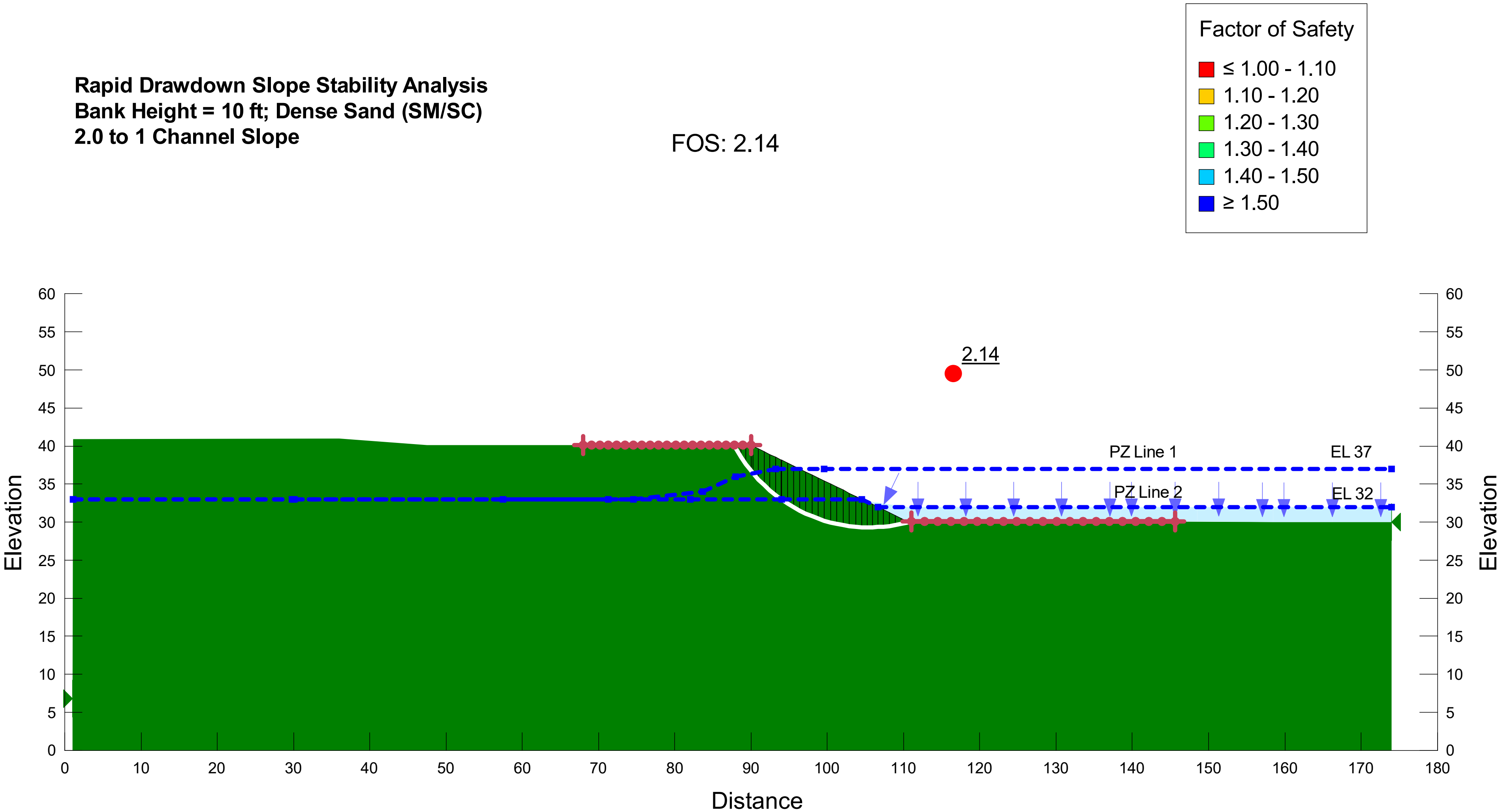
- ≤ 1.00 - 1.10
- 1.10 - 1.20
- 1.20 - 1.30
- 1.30 - 1.40
- 1.40 - 1.50
- ≥ 1.50



Color	Name	Unit Weight (pcf)	Effective Cohesion (psf)	Effective Friction Angle (°)	Cohesion R (psf)	Phi R (°)	Piezometric Surface	Piezometric Surface After Drawdown
	SM/SC Loose	120	100	28	110	20	1	2

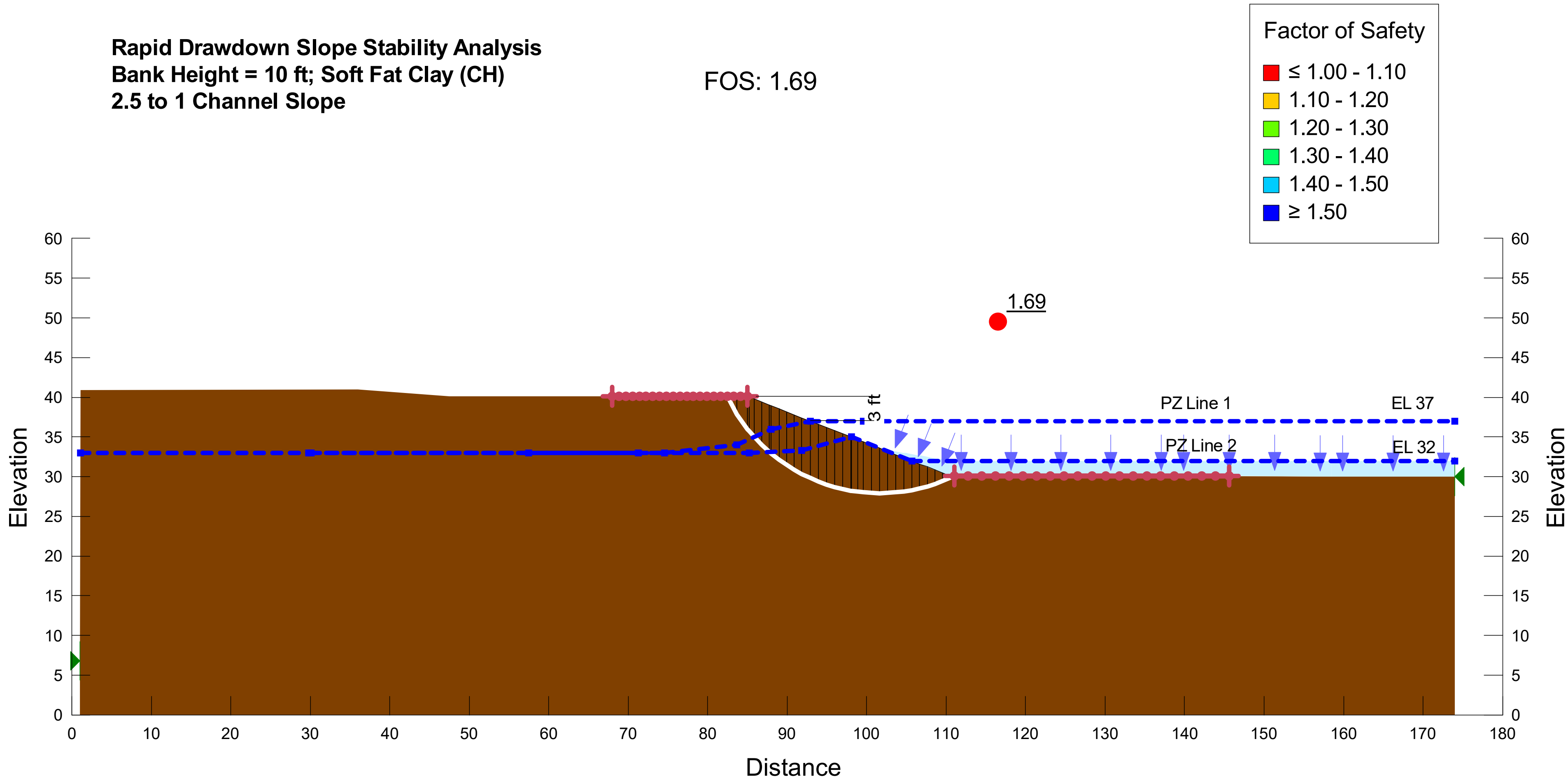
Rapid Drawdown Slope Stability Analysis
Bank Height = 10 ft; Dense Sand (SM/SC)
2.0 to 1 Channel Slope

FOS: 2.14



Color	Name	Unit Weight (pcf)	Effective Cohesion (psf)	Effective Friction Angle (°)	Cohesion R (psf)	Phi R (°)	Piezometric Surface	Piezometric Surface After Drawdown
	SM/SC Dense	120	100	35	150	27	1	2

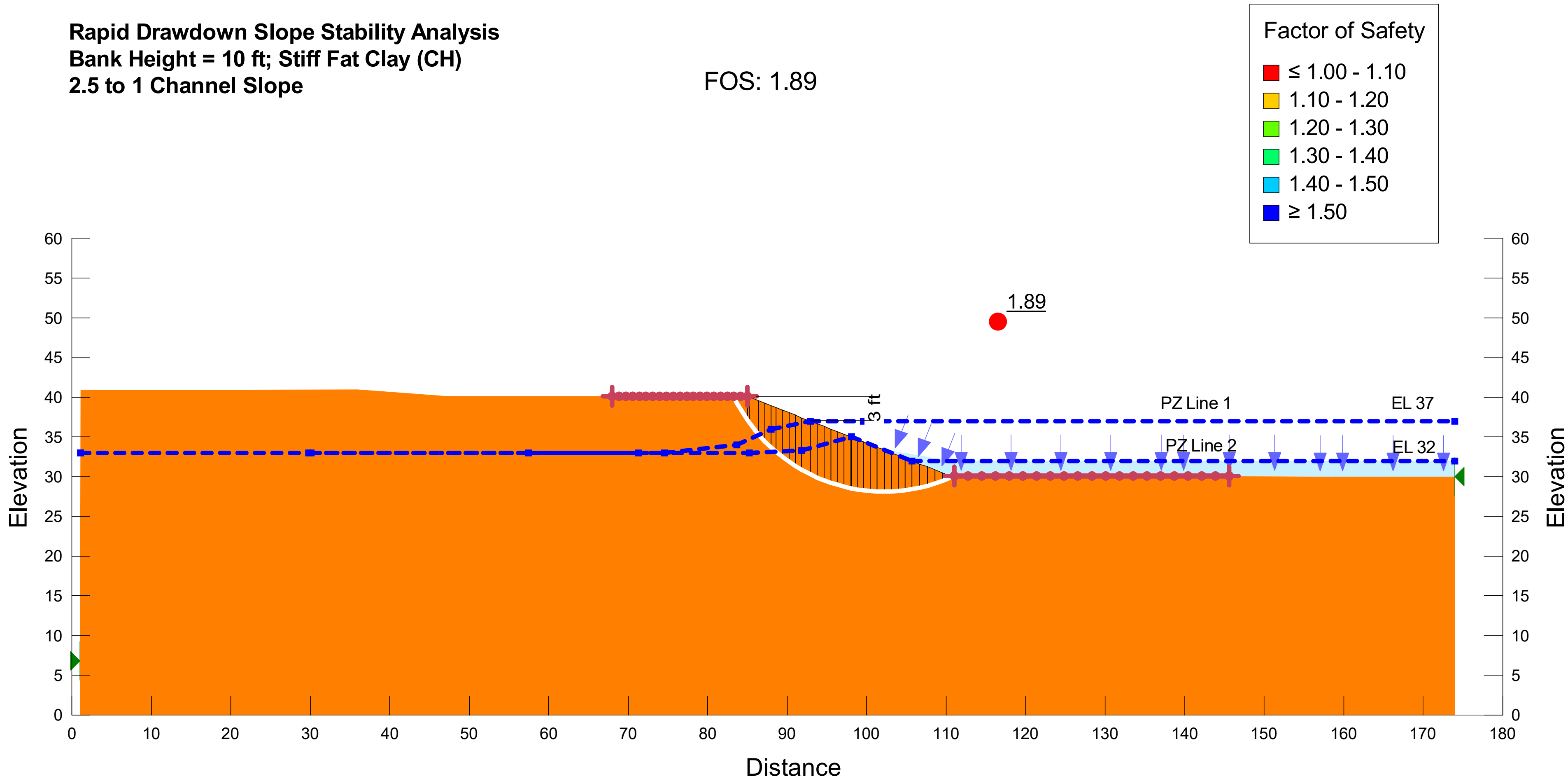
Rapid Drawdown Slope Stability Analysis
Bank Height = 10 ft; Soft Fat Clay (CH)
2.5 to 1 Channel Slope



Color	Name	Unit Weight (pcf)	Effective Cohesion (psf)	Effective Friction Angle (°)	Cohesion R (psf)	Phi R (°)	Piezometric Surface	Piezometric Surface After Drawdown
	CH Soft	120	100	22	500	0	1	2

Rapid Drawdown Slope Stability Analysis
Bank Height = 10 ft; Stiff Fat Clay (CH)
2.5 to 1 Channel Slope

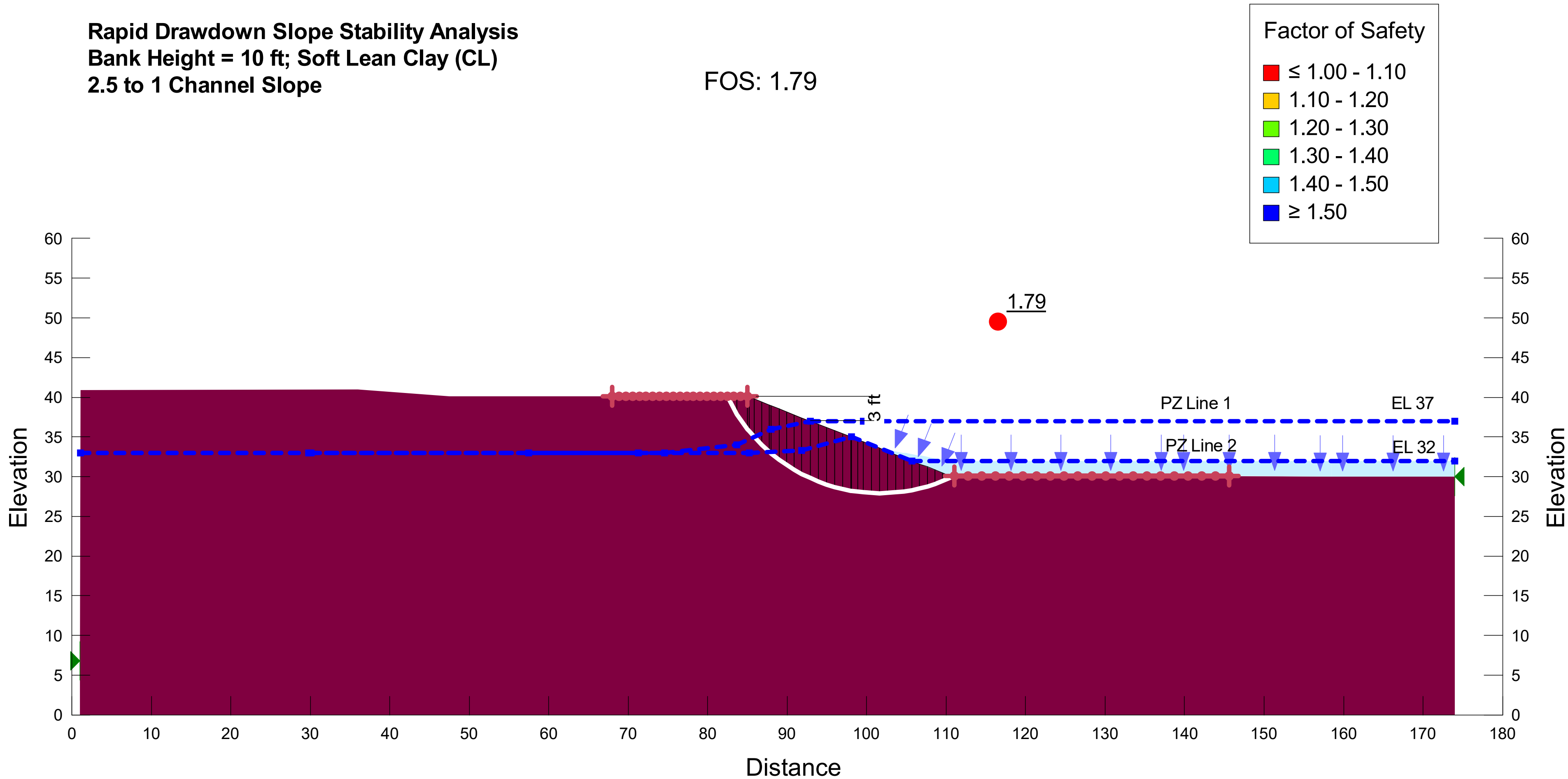
FOS: 1.89



Color	Name	Unit Weight (pcf)	Effective Cohesion (psf)	Effective Friction Angle (°)	Cohesion R (psf)	Phi R (°)	Piezometric Surface	Piezometric Surface After Drawdown
	CH Stiff	120	100	26	2,000	0	1	2

Rapid Drawdown Slope Stability Analysis
Bank Height = 10 ft; Soft Lean Clay (CL)
2.5 to 1 Channel Slope

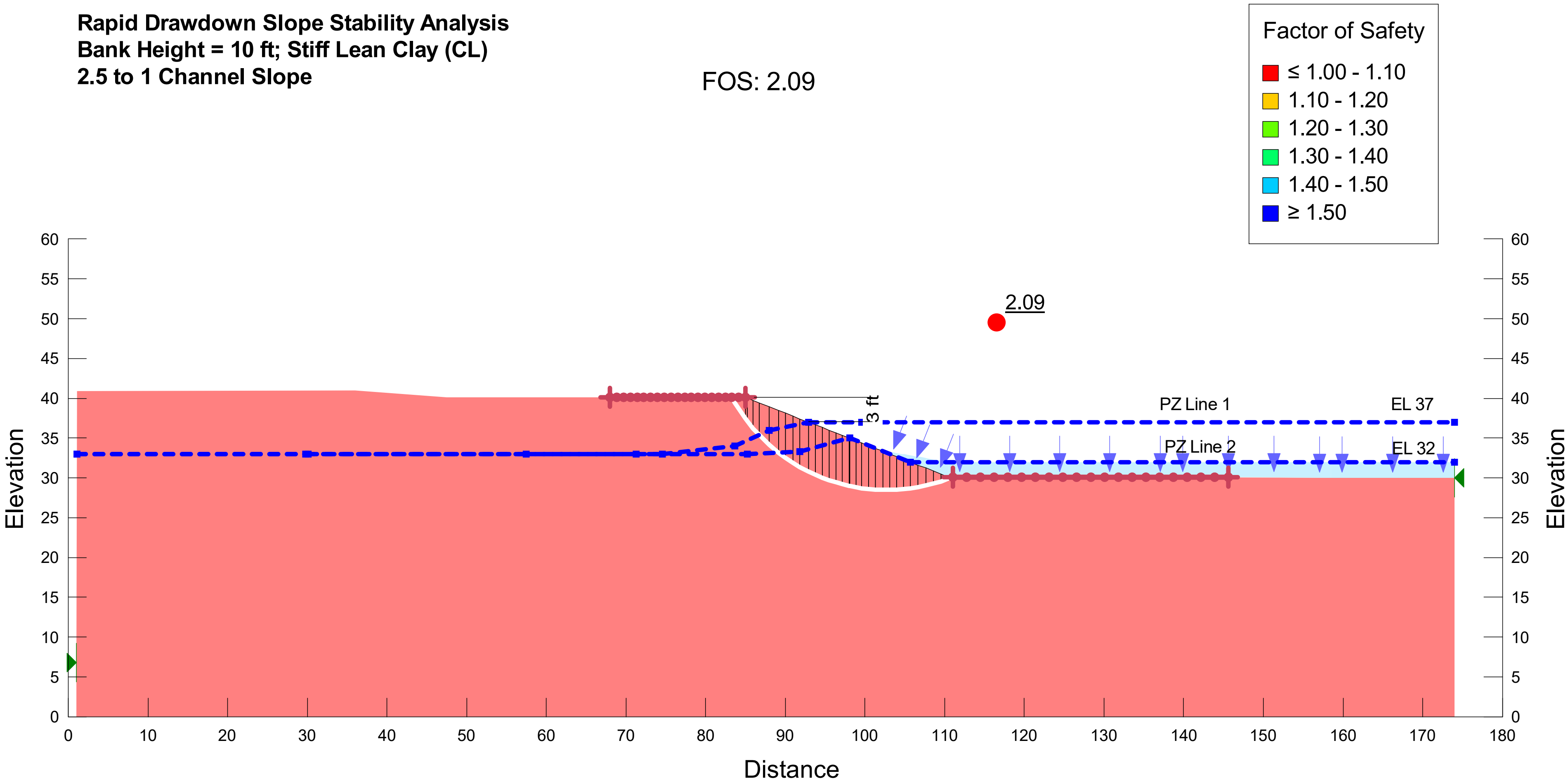
FOS: 1.79



Color	Name	Unit Weight (pcf)	Effective Cohesion (psf)	Effective Friction Angle (°)	Cohesion R (psf)	Phi R (°)	Piezometric Surface	Piezometric Surface After Drawdown
	CL Soft	120	100	24	500	0	1	2

Rapid Drawdown Slope Stability Analysis
Bank Height = 10 ft; Stiff Lean Clay (CL)
2.5 to 1 Channel Slope

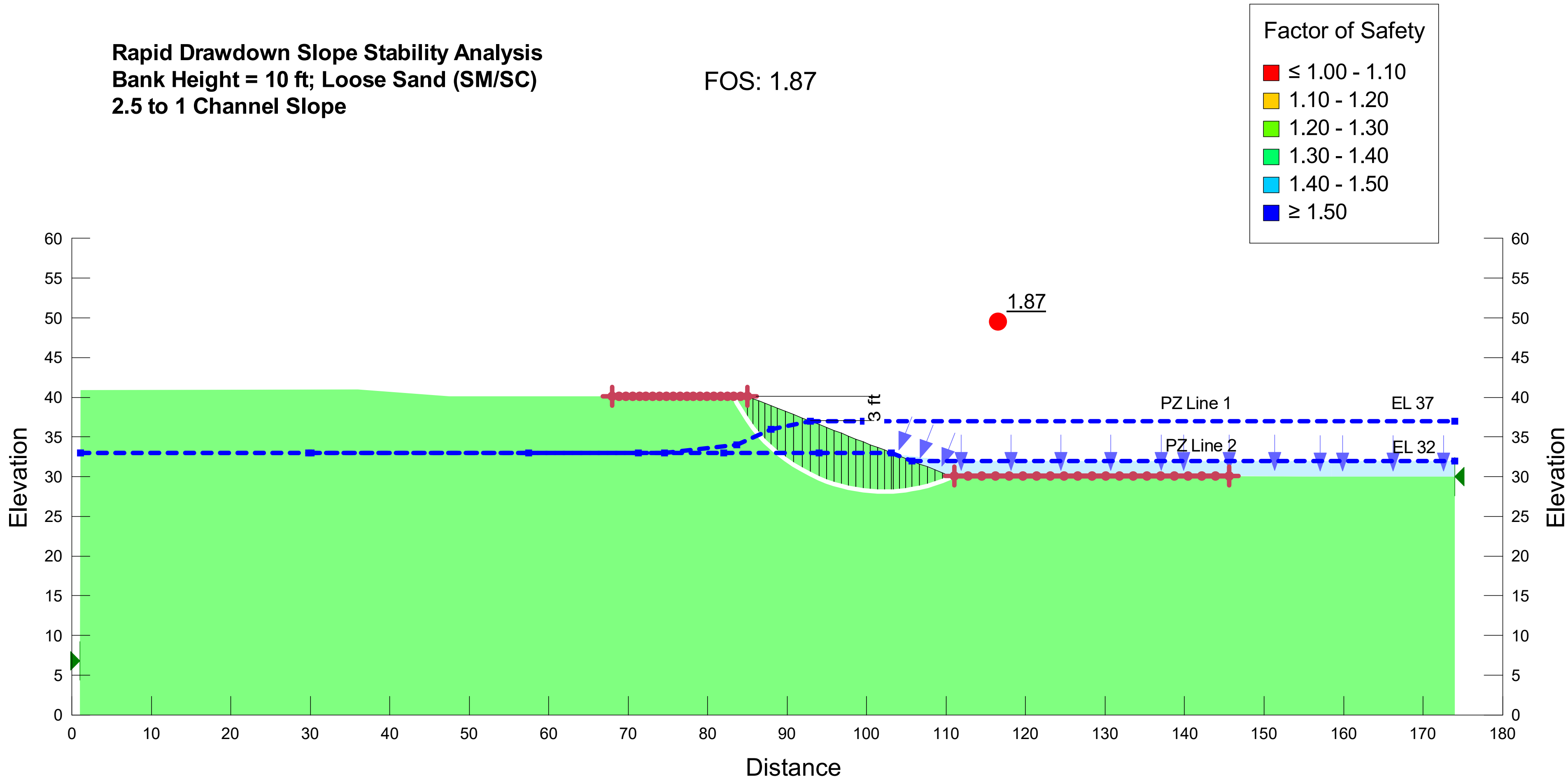
FOS: 2.09



Color	Name	Unit Weight (pcf)	Effective Cohesion (psf)	Effective Friction Angle (°)	Cohesion R (psf)	Phi R (°)	Piezometric Surface	Piezometric Surface After Drawdown
	CL Stiff	120	100	30	2,000	0	1	2

Rapid Drawdown Slope Stability Analysis
Bank Height = 10 ft; Loose Sand (SM/SC)
2.5 to 1 Channel Slope

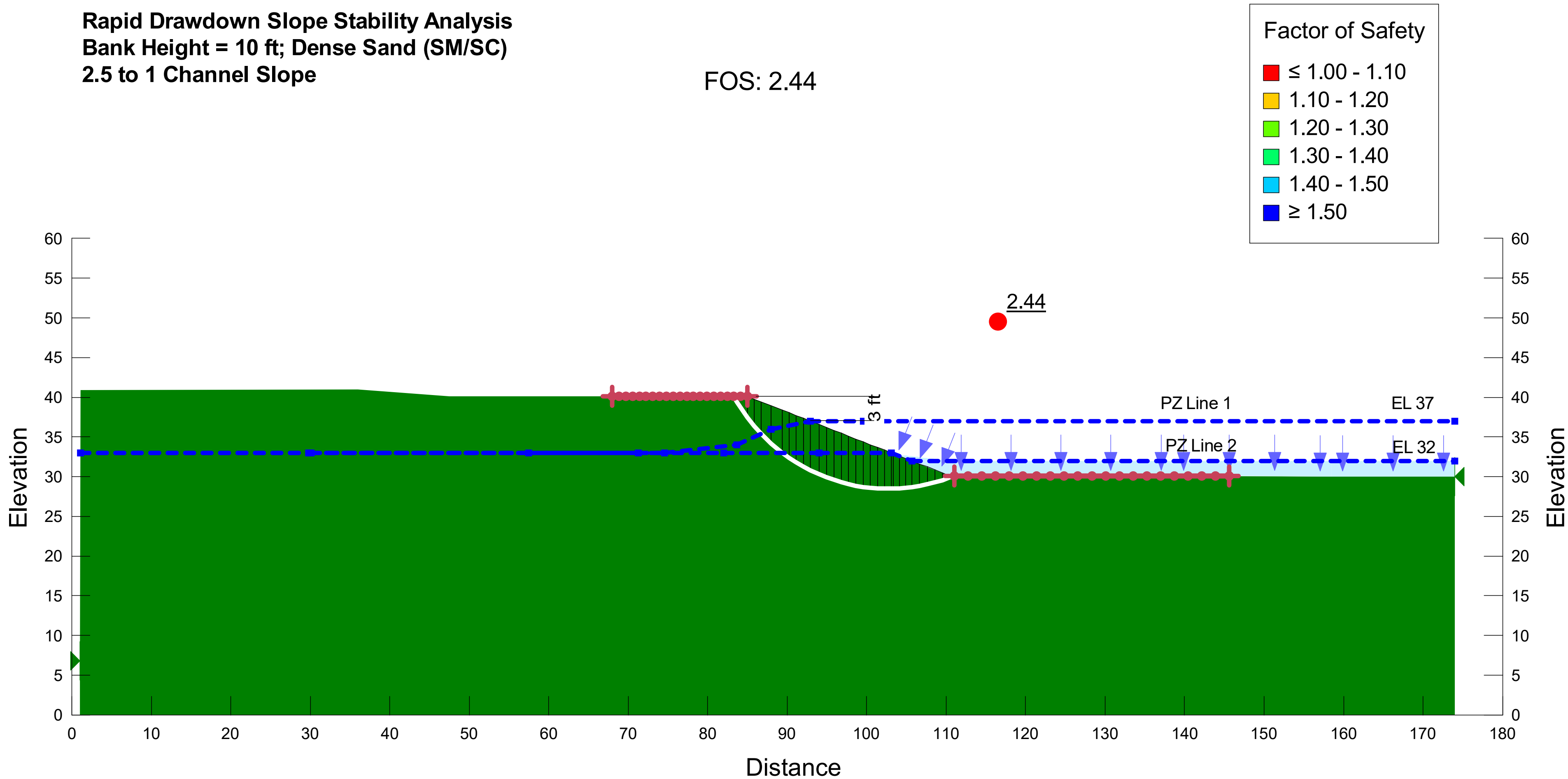
FOS: 1.87



Color	Name	Unit Weight (pcf)	Effective Cohesion (psf)	Effective Friction Angle (°)	Cohesion R (psf)	Phi R (°)	Piezometric Surface	Piezometric Surface After Drawdown
	SM/SC Loose	120	100	28	110	20	1	2

Rapid Drawdown Slope Stability Analysis
Bank Height = 10 ft; Dense Sand (SM/SC)
2.5 to 1 Channel Slope

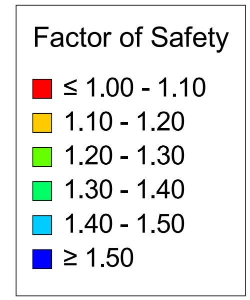
FOS: 2.44

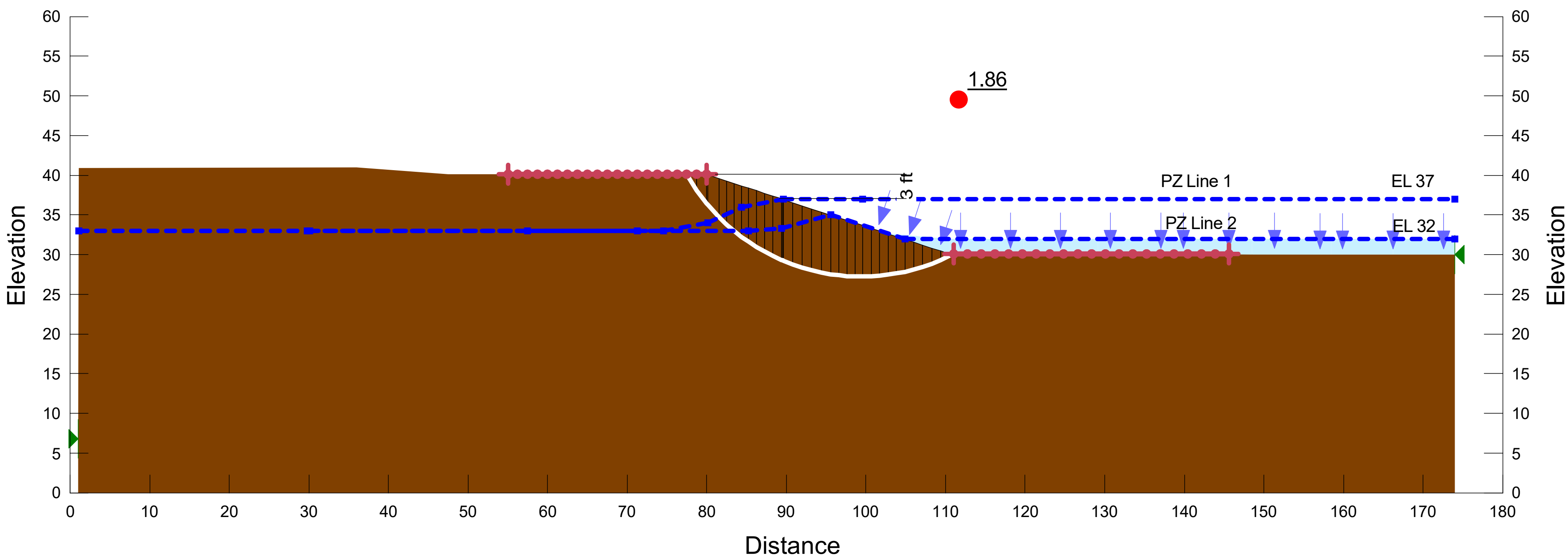


Color	Name	Unit Weight (pcf)	Effective Cohesion (psf)	Effective Friction Angle (°)	Cohesion R (psf)	Phi R (°)	Piezometric Surface	Piezometric Surface After Drawdown
	SM/SC Dense	120	100	35	150	27	1	2

Rapid Drawdown Slope Stability Analysis
Bank Height = 10 ft; Soft Fat Clay (CH)
3.0 to 1 Channel Slope

FOS: 1.86

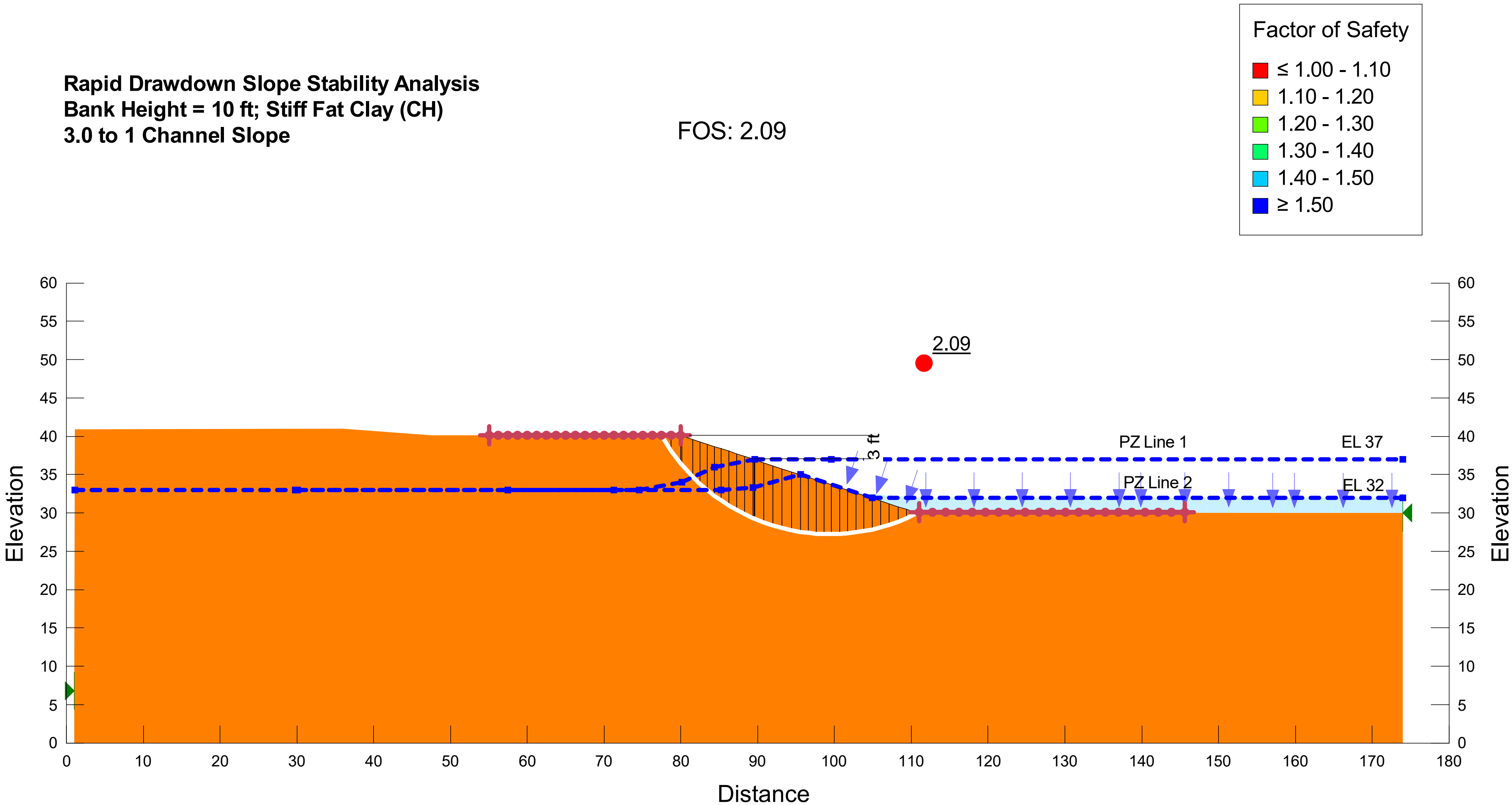




Color	Name	Unit Weight (pcf)	Effective Cohesion (psf)	Effective Friction Angle (°)	Cohesion R (psf)	Phi R (°)	Piezometric Surface	Piezometric Surface After Drawdown
	CH Soft	120	100	22	500	0	1	2

Rapid Drawdown Slope Stability Analysis
Bank Height = 10 ft; Stiff Fat Clay (CH)
3.0 to 1 Channel Slope

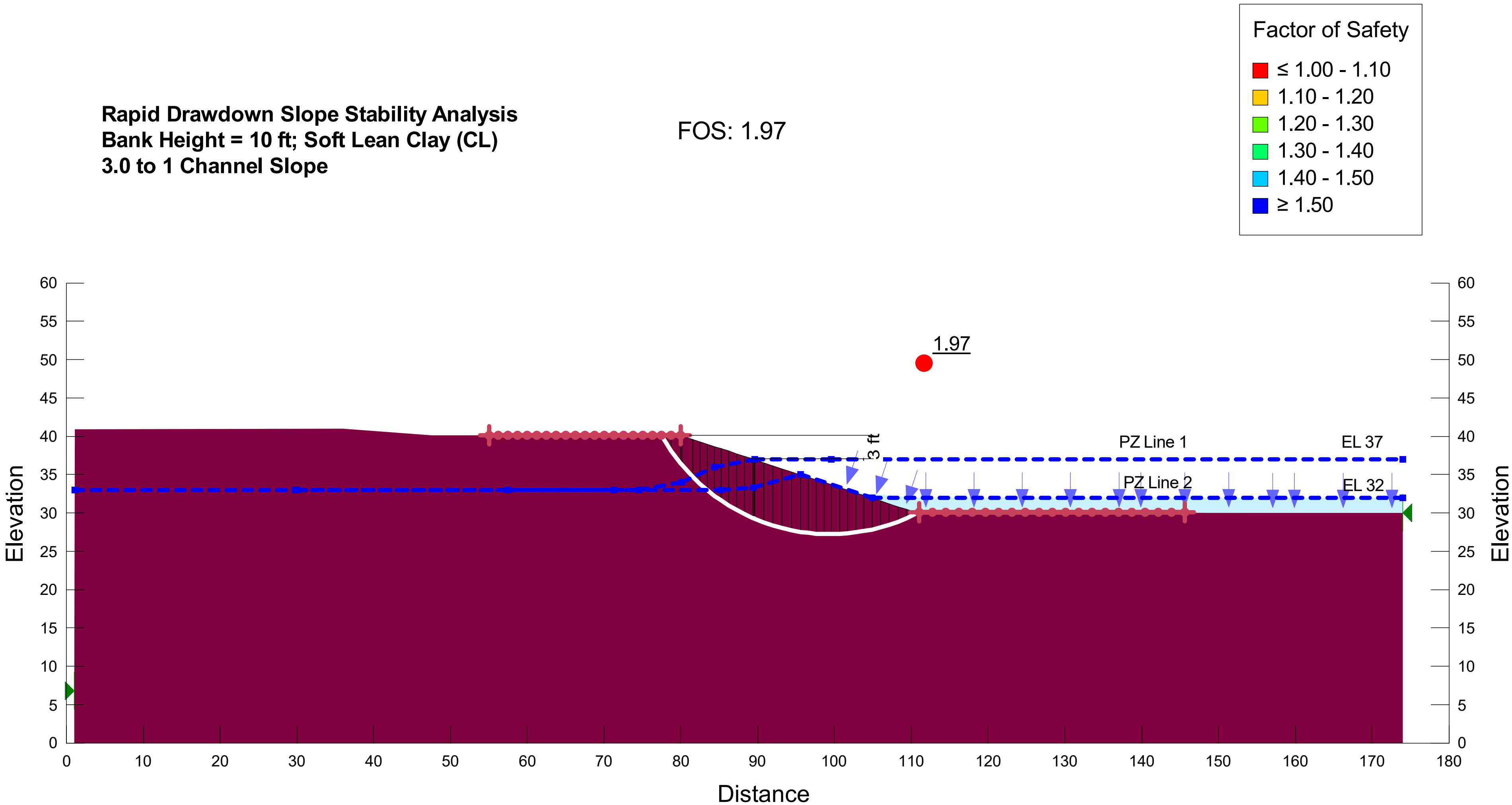
FOS: 2.09



Color	Name	Unit Weight (pcf)	Effective Cohesion (psf)	Effective Friction Angle (°)	Cohesion R (psf)	Phi R (°)	Piezometric Surface	Piezometric Surface After Drawdown
	CH Stiff	120	100	26	2,000	0	1	2

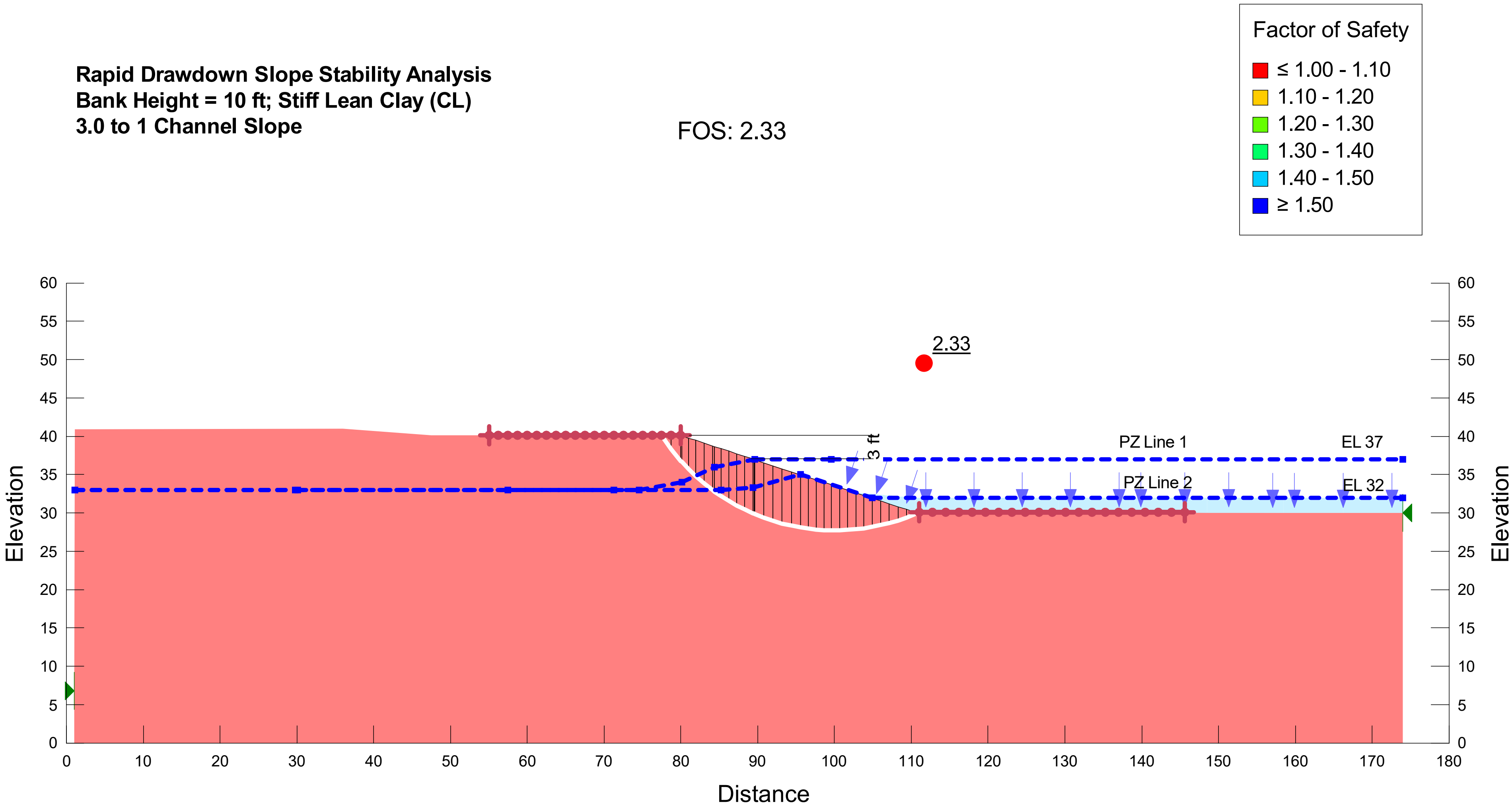
Rapid Drawdown Slope Stability Analysis
Bank Height = 10 ft; Soft Lean Clay (CL)
3.0 to 1 Channel Slope

FOS: 1.97



Color	Name	Unit Weight (pcf)	Effective Cohesion (psf)	Effective Friction Angle (°)	Cohesion R (psf)	Phi R (°)	Piezometric Surface	Piezometric Surface After Drawdown
	CL Soft	120	100	24	500	0	1	2

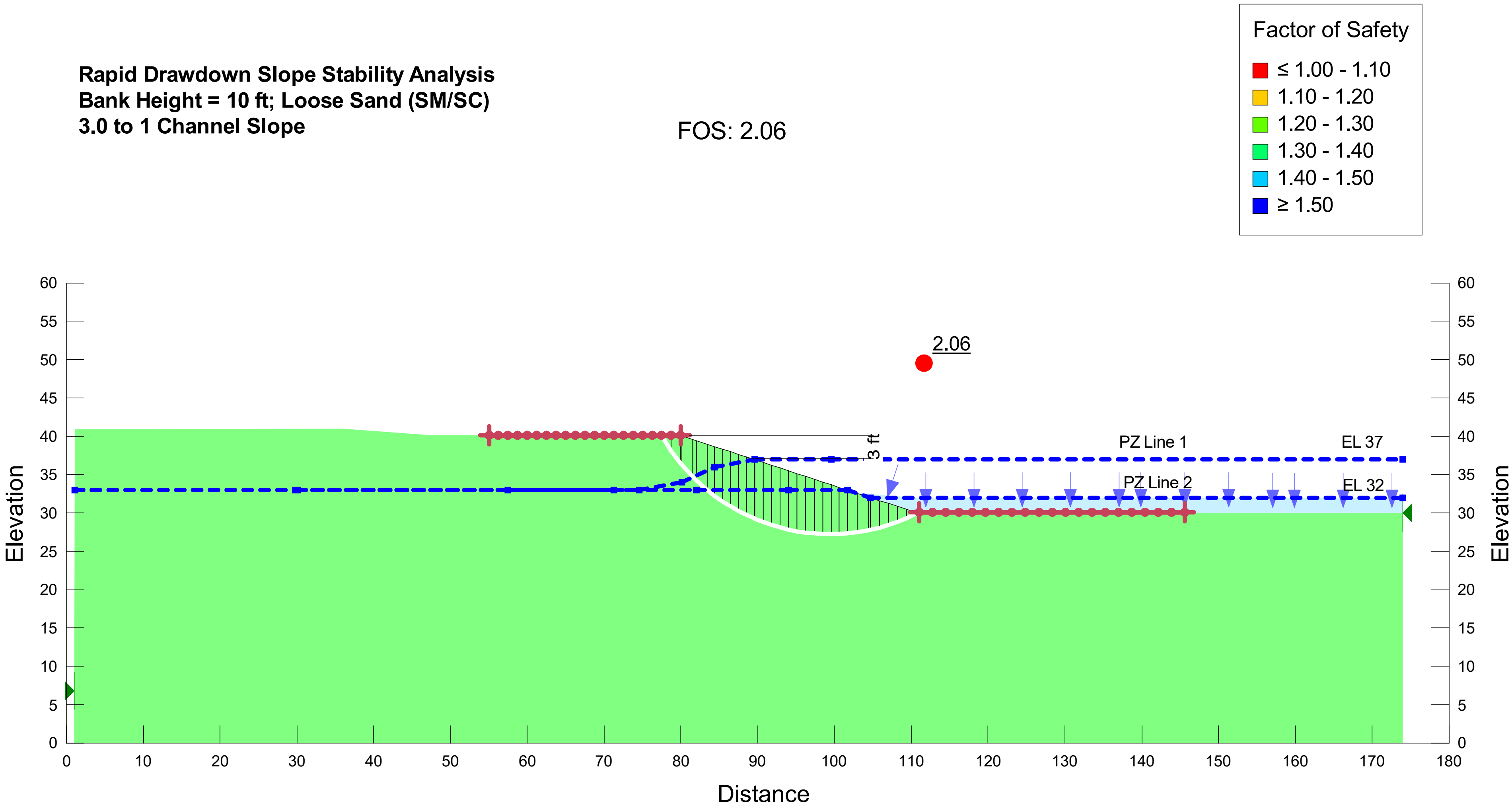
Rapid Drawdown Slope Stability Analysis
Bank Height = 10 ft; Stiff Lean Clay (CL)
3.0 to 1 Channel Slope



Color	Name	Unit Weight (pcf)	Effective Cohesion (psf)	Effective Friction Angle (°)	Cohesion R (psf)	Phi R (°)	Piezometric Surface	Piezometric Surface After Drawdown
	CL Stiff	120	100	30	2,000	0	1	2

Rapid Drawdown Slope Stability Analysis
Bank Height = 10 ft; Loose Sand (SM/SC)
3.0 to 1 Channel Slope

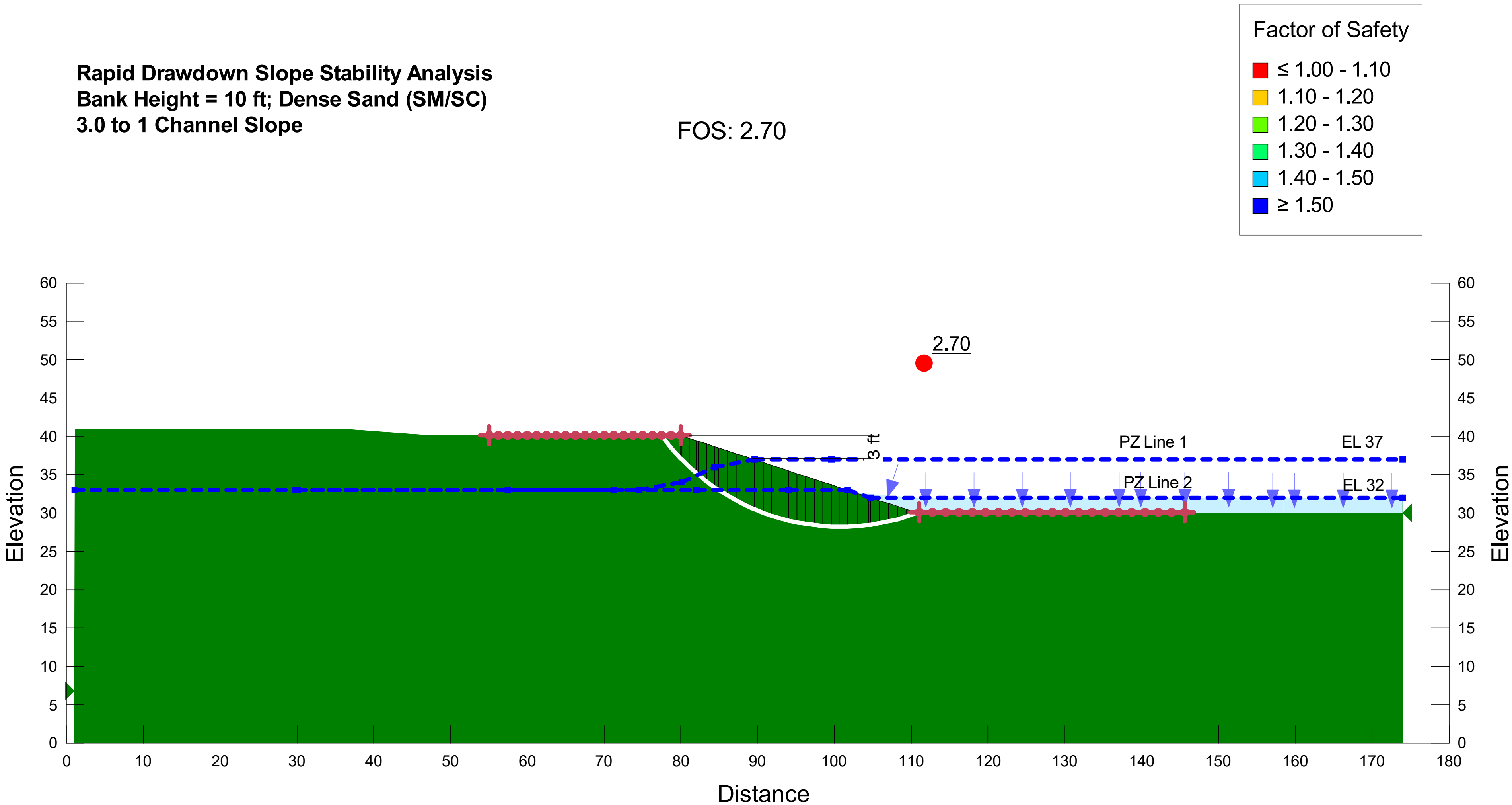
FOS: 2.06



Color	Name	Unit Weight (pcf)	Effective Cohesion (psf)	Effective Friction Angle (°)	Cohesion R (psf)	Phi R (°)	Piezometric Surface	Piezometric Surface After Drawdown
	SM/SC Loose	120	100	28	110	20	1	2

Rapid Drawdown Slope Stability Analysis
Bank Height = 10 ft; Dense Sand (SM/SC)
3.0 to 1 Channel Slope

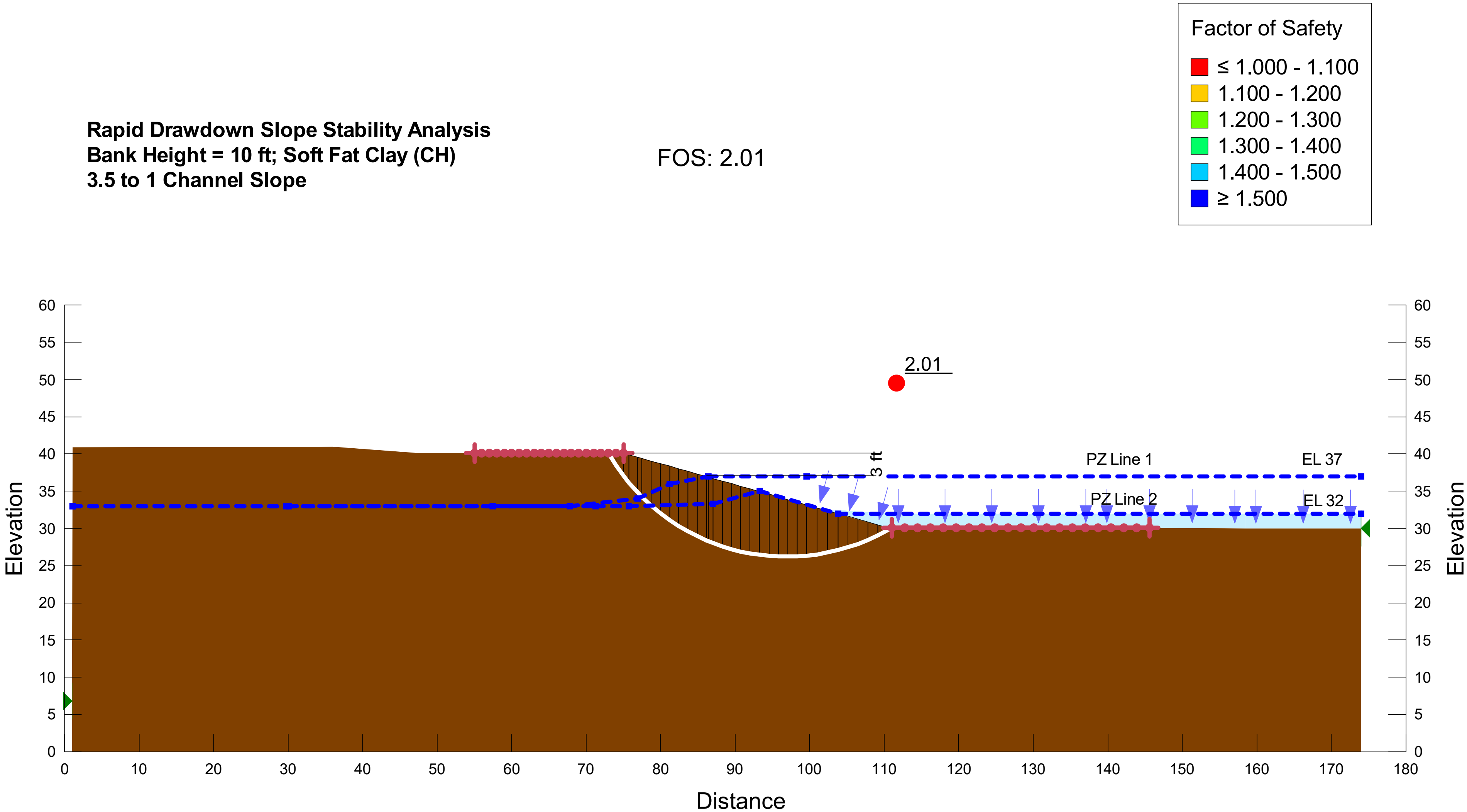
FOS: 2.70



Color	Name	Unit Weight (pcf)	Effective Cohesion (psf)	Effective Friction Angle (°)	Cohesion R (psf)	Phi R (°)	Piezometric Surface	Piezometric Surface After Drawdown
	SM/SC Dense	120	100	35	150	27	1	2

Rapid Drawdown Slope Stability Analysis
Bank Height = 10 ft; Soft Fat Clay (CH)
3.5 to 1 Channel Slope

FOS: 2.01



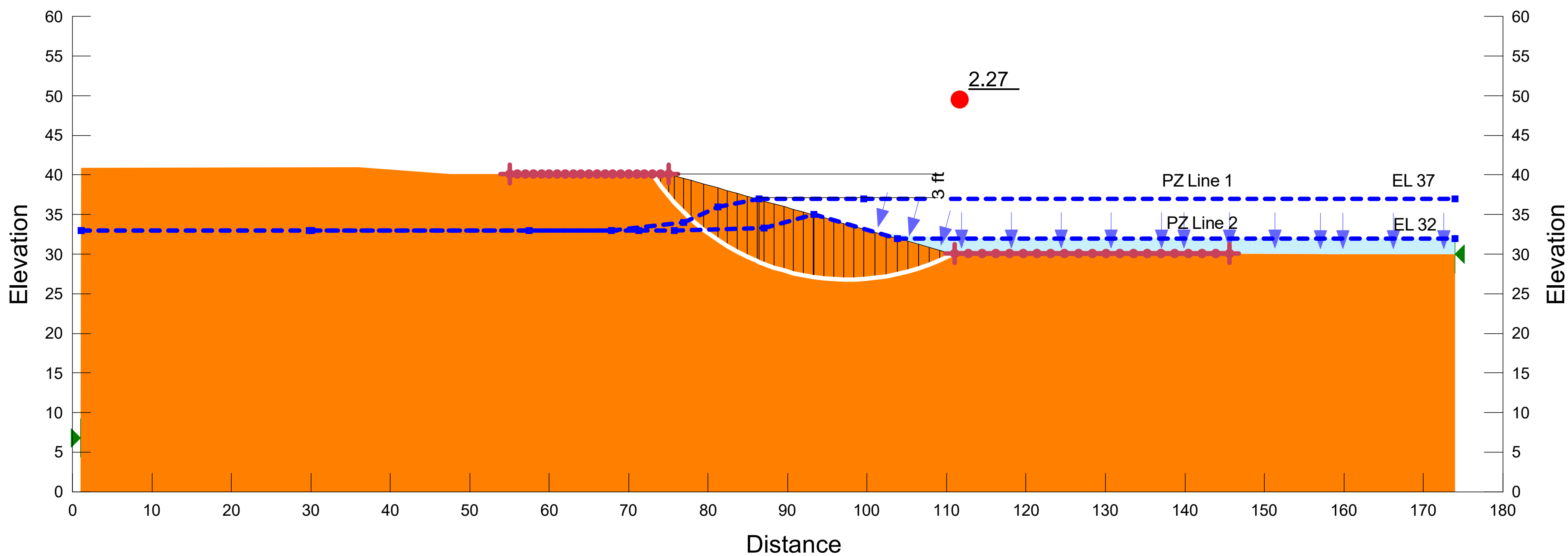
Color	Name	Unit Weight (pcf)	Effective Cohesion (psf)	Effective Friction Angle (°)	Cohesion R (psf)	Phi R (°)	Piezometric Surface	Piezometric Surface After Drawdown
	CH Soft	120	100	22	500	0	1	2

Rapid Drawdown Slope Stability Analysis
Bank Height = 10 ft; Stiff Fat Clay (CH)
3.5 to 1 Channel Slope

FOS: 2.27

Factor of Safety

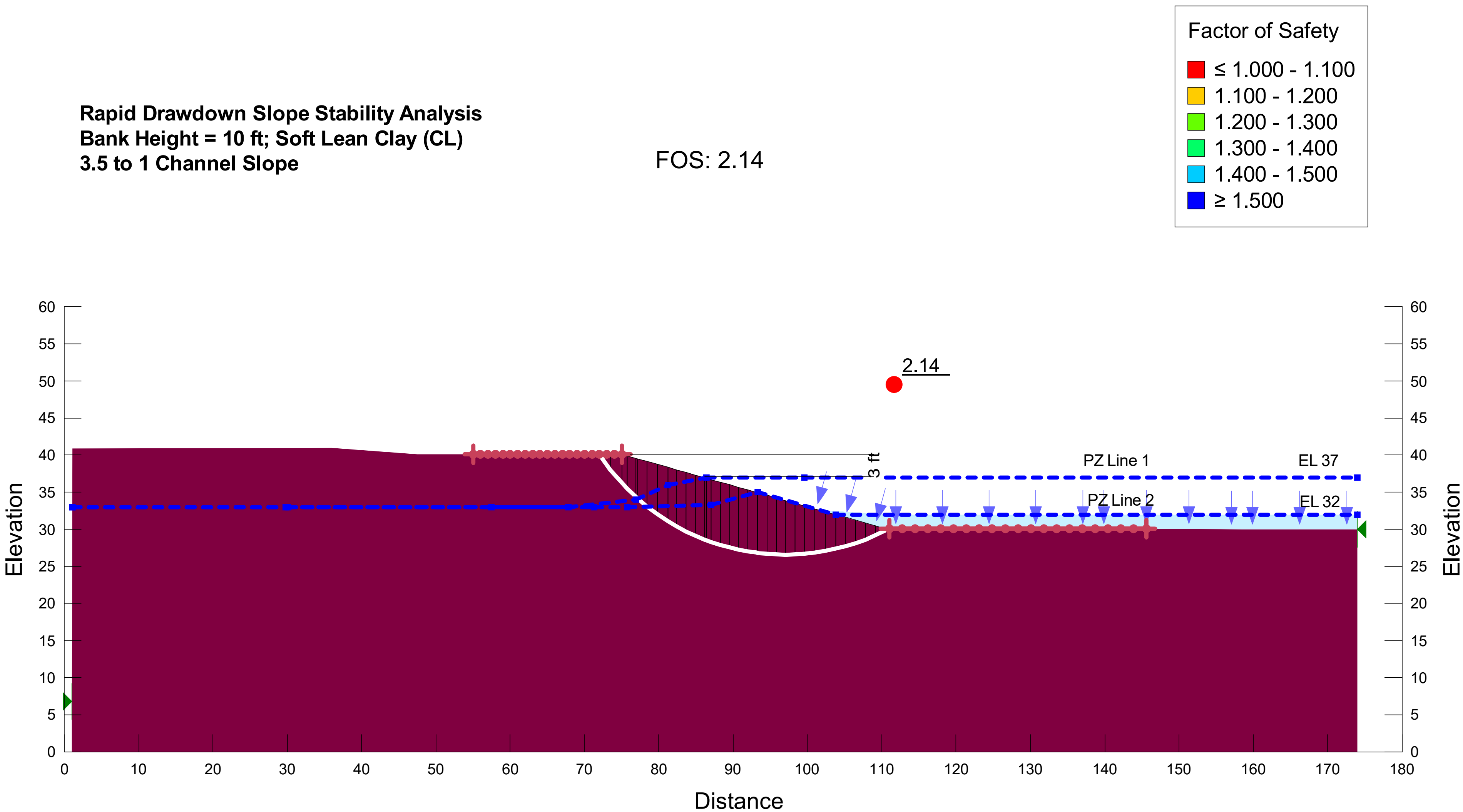
- ≤ 1.000 - 1.100
- 1.100 - 1.200
- 1.200 - 1.300
- 1.300 - 1.400
- 1.400 - 1.500
- ≥ 1.500



Color	Name	Unit Weight (pcf)	Effective Cohesion (psf)	Effective Friction Angle (°)	Cohesion R (psf)	Phi R (°)	Piezometric Surface	Piezometric Surface After Drawdown
	CH Stiff	120	100	26	2,000	0	1	2

Rapid Drawdown Slope Stability Analysis
Bank Height = 10 ft; Soft Lean Clay (CL)
3.5 to 1 Channel Slope

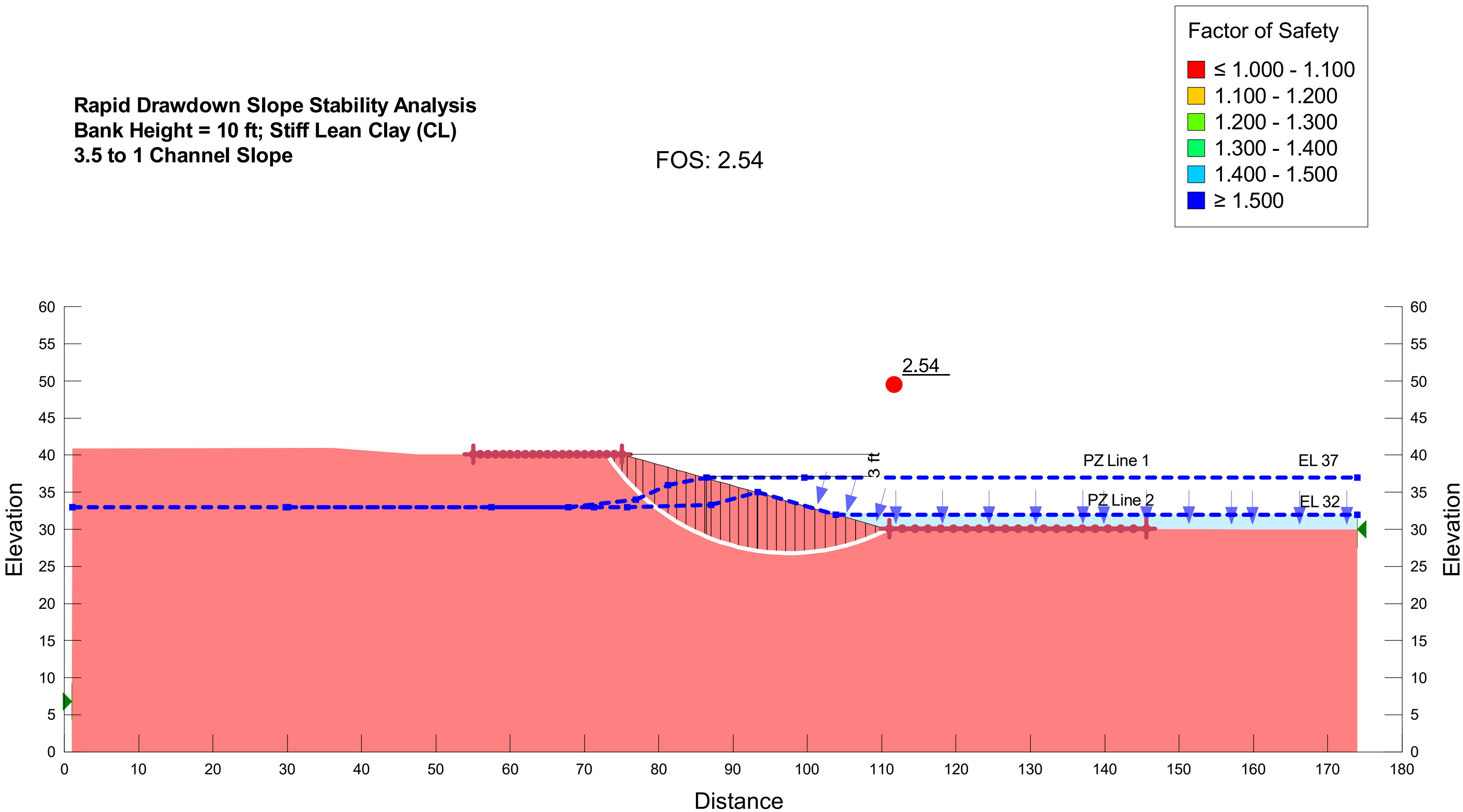
FOS: 2.14



Color	Name	Unit Weight (pcf)	Effective Cohesion (psf)	Effective Friction Angle (°)	Cohesion R (psf)	Phi R (°)	Piezometric Surface	Piezometric Surface After Drawdown
	CL Soft	120	100	24	500	0	1	2

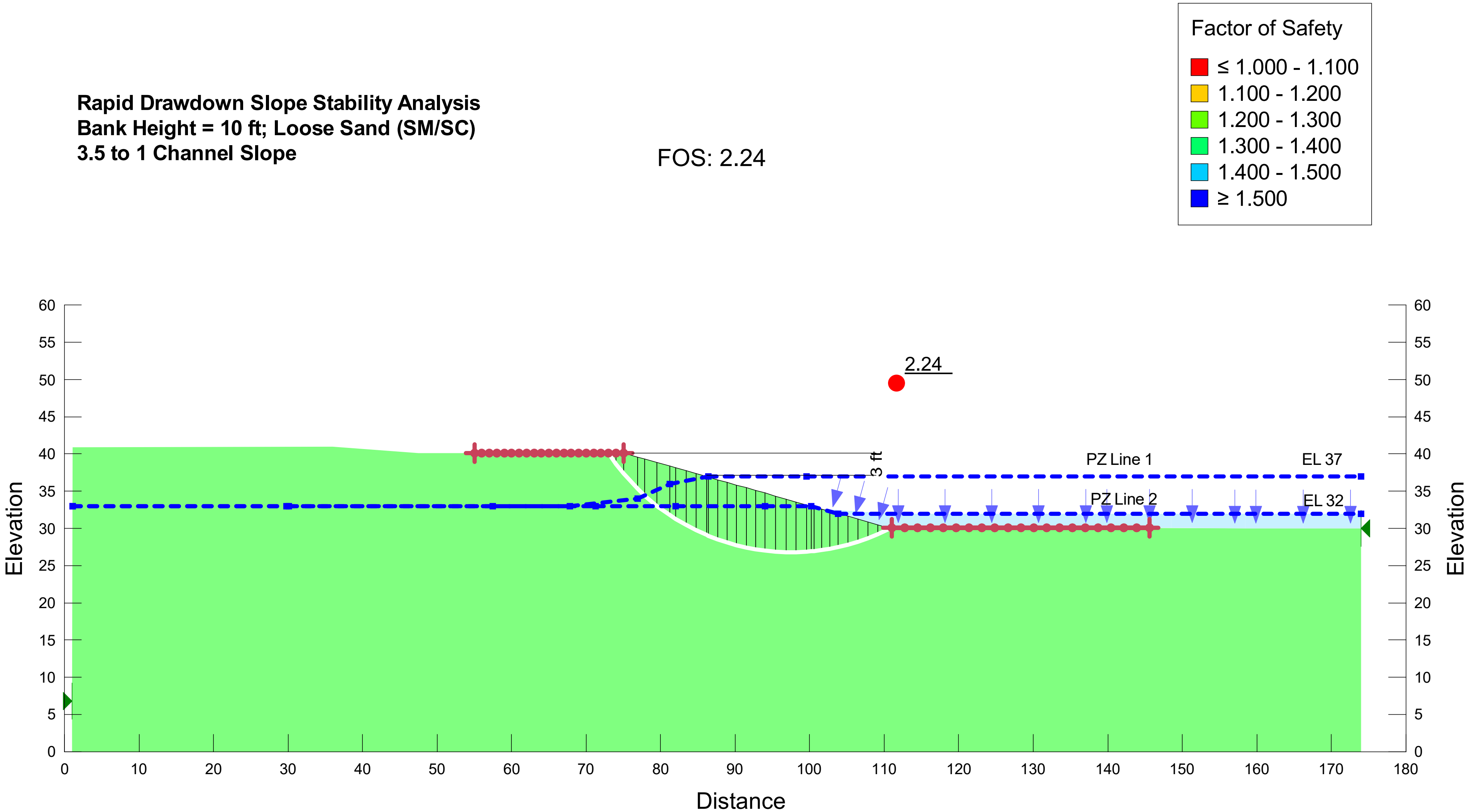
Rapid Drawdown Slope Stability Analysis
Bank Height = 10 ft; Stiff Lean Clay (CL)
3.5 to 1 Channel Slope

FOS: 2.54



Color	Name	Unit Weight (pcf)	Effective Cohesion (psf)	Effective Friction Angle (°)	Cohesion R (psf)	Phi R (°)	Piezometric Surface	Piezometric Surface After Drawdown
	CL Stiff	120	100	30	2,000	0	1	2

Rapid Drawdown Slope Stability Analysis
Bank Height = 10 ft; Loose Sand (SM/SC)
3.5 to 1 Channel Slope



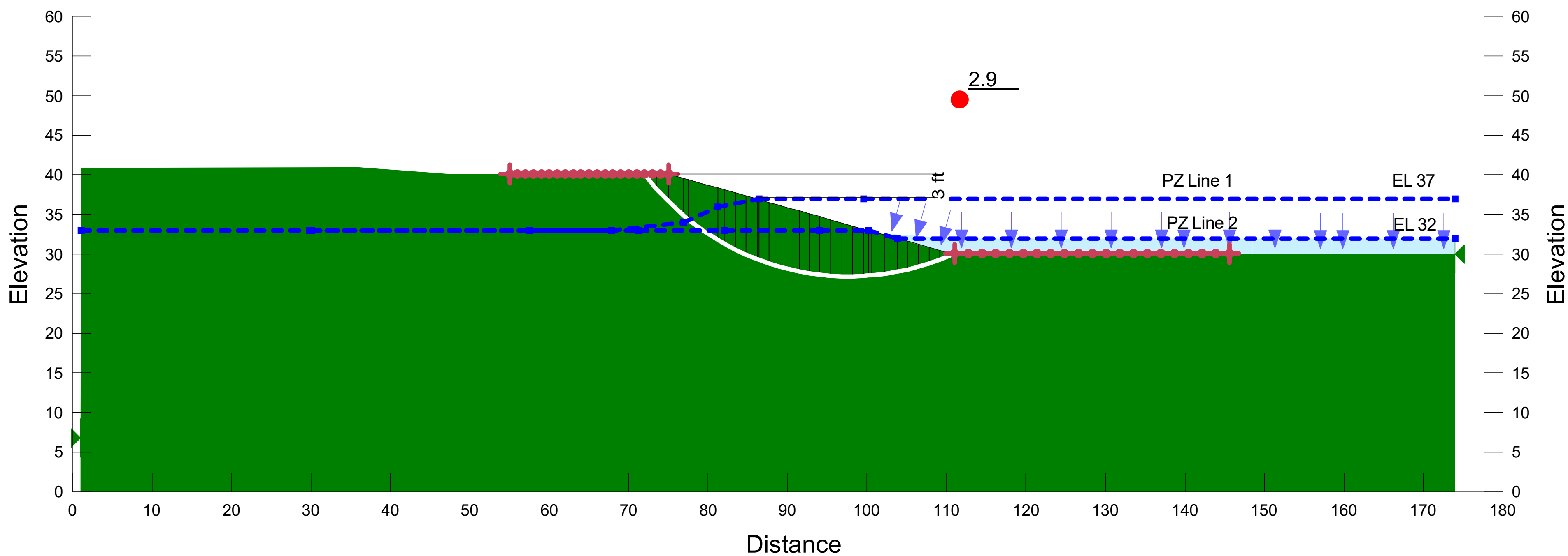
Color	Name	Unit Weight (pcf)	Effective Cohesion (psf)	Effective Friction Angle (°)	Cohesion R (psf)	Phi R (°)	Piezometric Surface	Piezometric Surface After Drawdown
	SM/SC Loose	120	100	28	110	20	1	2

Rapid Drawdown Slope Stability Analysis
Bank Height = 10 ft; Dense Sand (SM/SC)
3.5 to 1 Channel Slope

FOS: 2.9

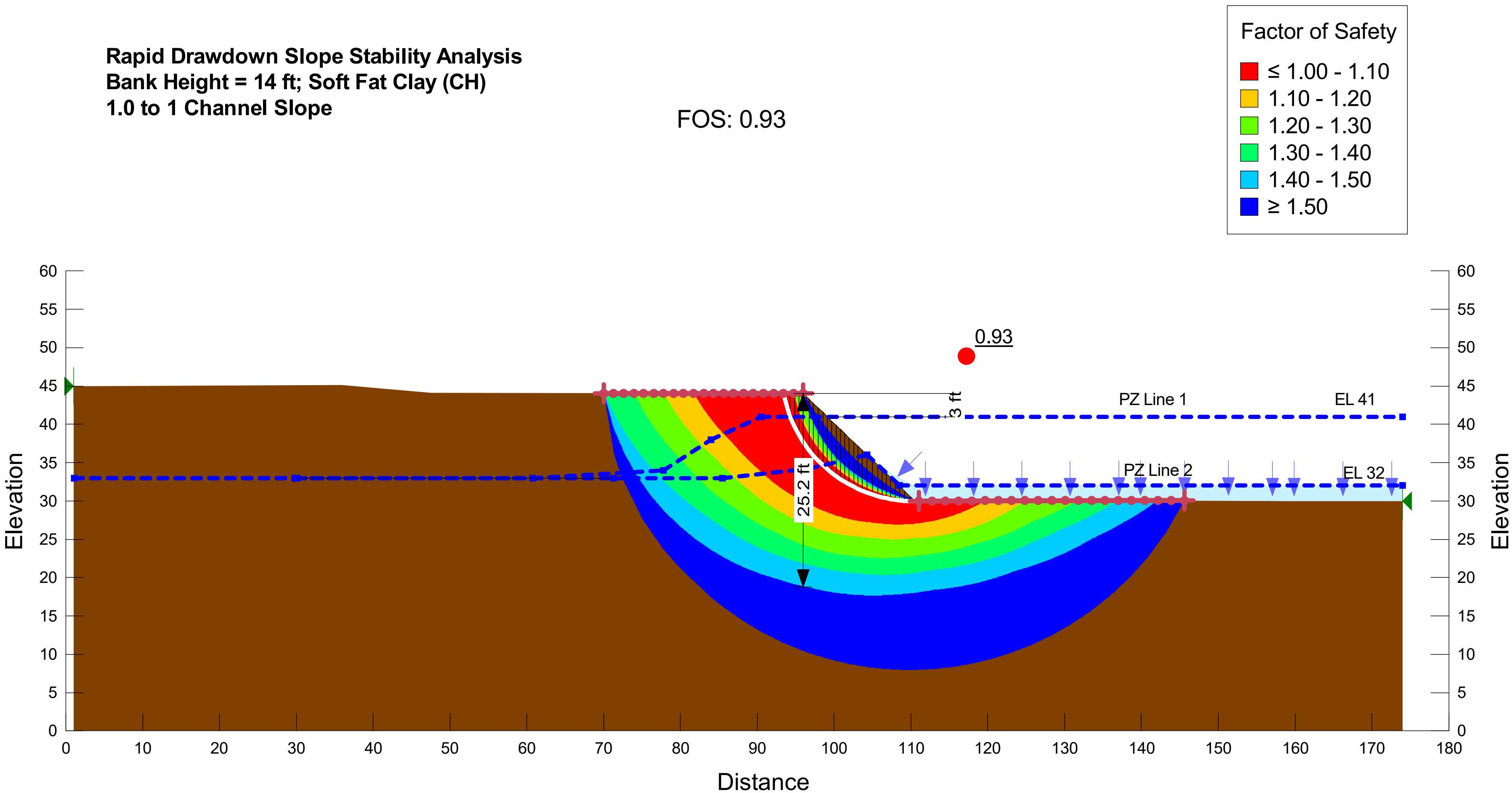
Factor of Safety

- ≤ 1.000 - 1.100
- 1.100 - 1.200
- 1.200 - 1.300
- 1.300 - 1.400
- 1.400 - 1.500
- ≥ 1.500



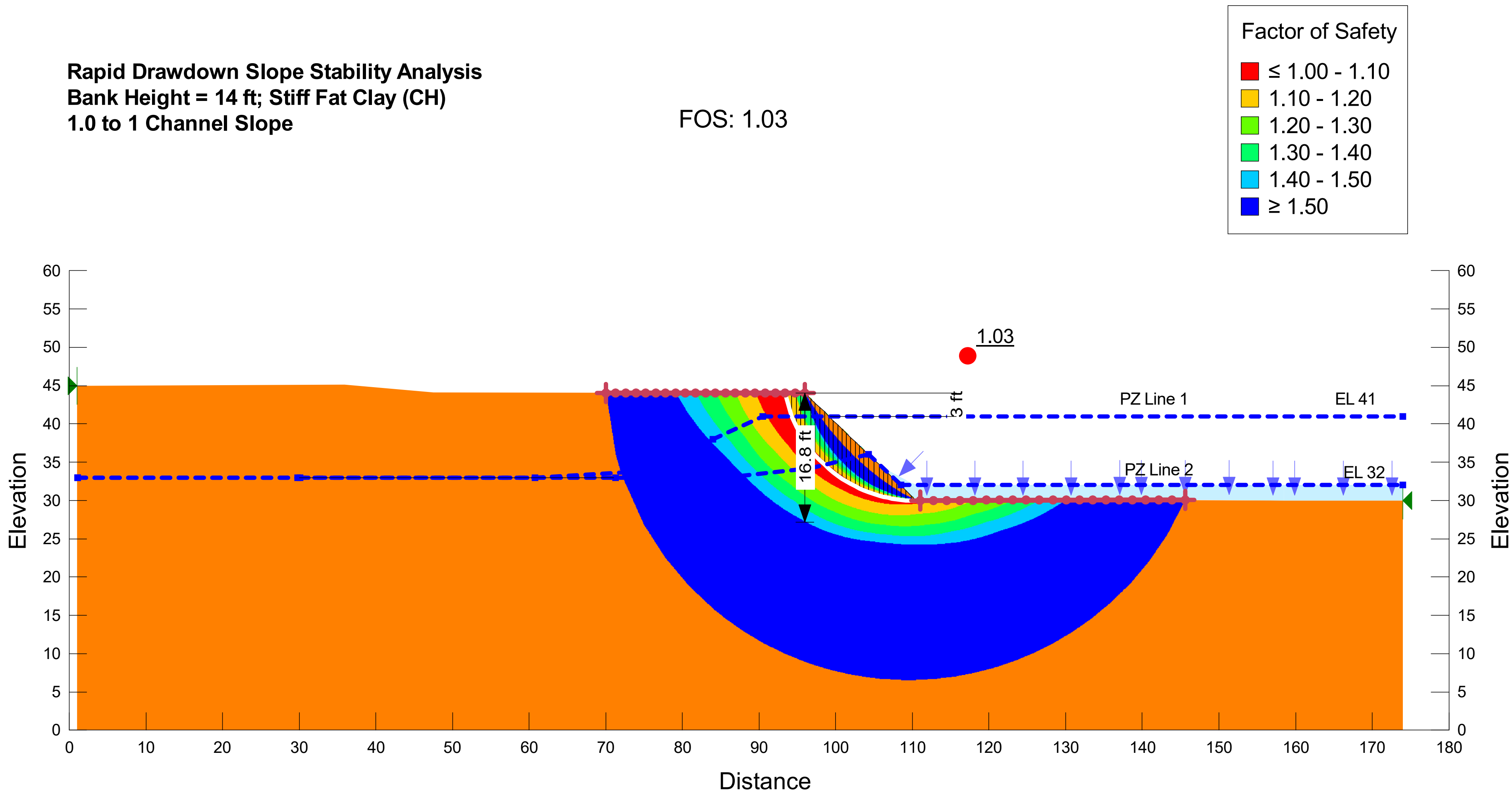
Color	Name	Unit Weight (pcf)	Effective Cohesion (psf)	Effective Friction Angle (°)	Cohesion R (psf)	Phi R (°)	Piezometric Surface	Piezometric Surface After Drawdown
	SM/SC Dense	120	100	35	150	27	1	2

Rapid Drawdown Slope Stability Analysis
Bank Height = 14 ft; Soft Fat Clay (CH)
1.0 to 1 Channel Slope

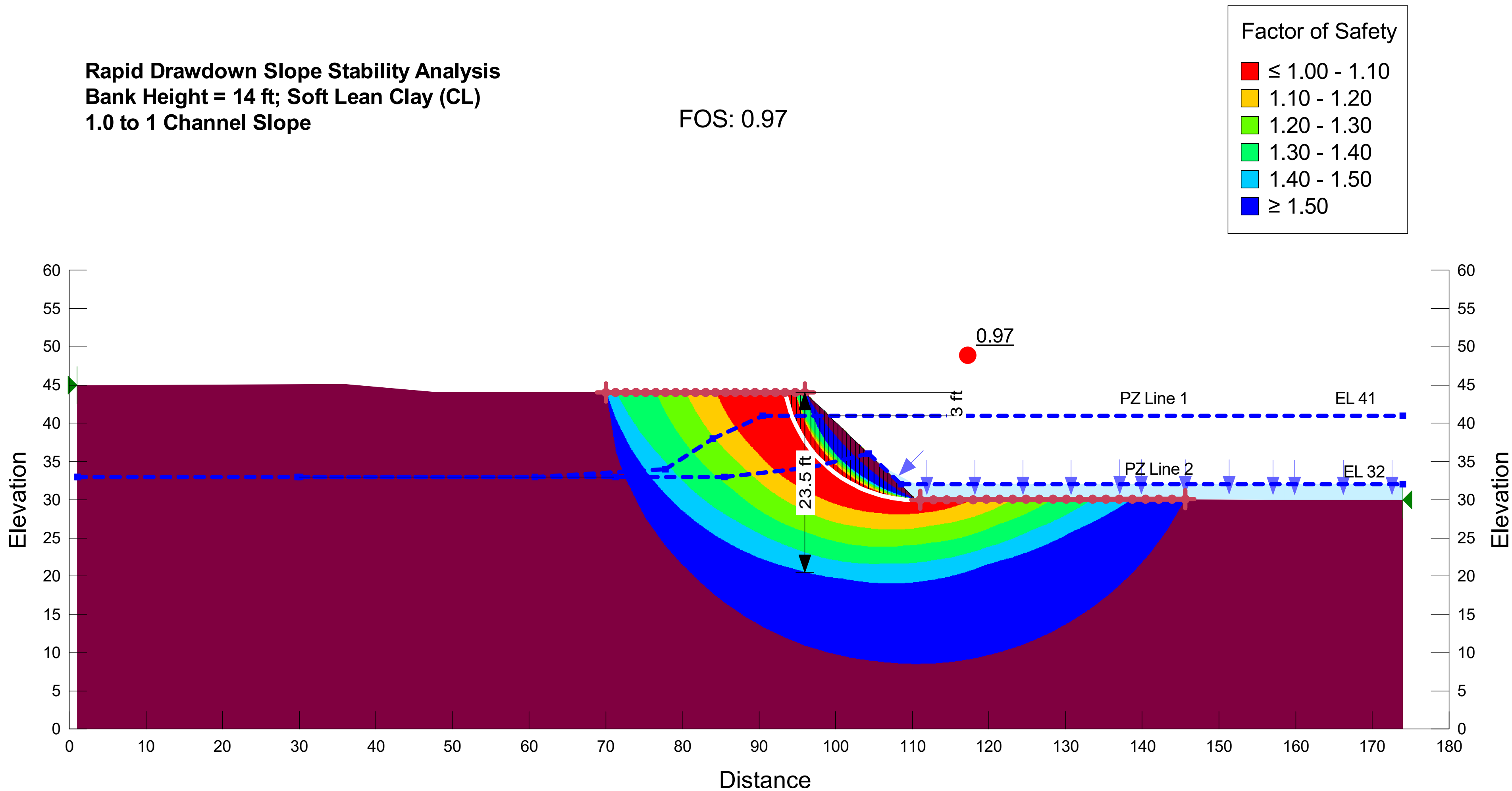


Color	Name	Unit Weight (pcf)	Effective Cohesion (psf)	Effective Friction Angle (°)	Cohesion R (psf)	Phi R (°)	Piezometric Surface	Piezometric Surface After Drawdown
	CH Soft	120	100	22	500	0	1	2

Rapid Drawdown Slope Stability Analysis
Bank Height = 14 ft; Stiff Fat Clay (CH)
1.0 to 1 Channel Slope



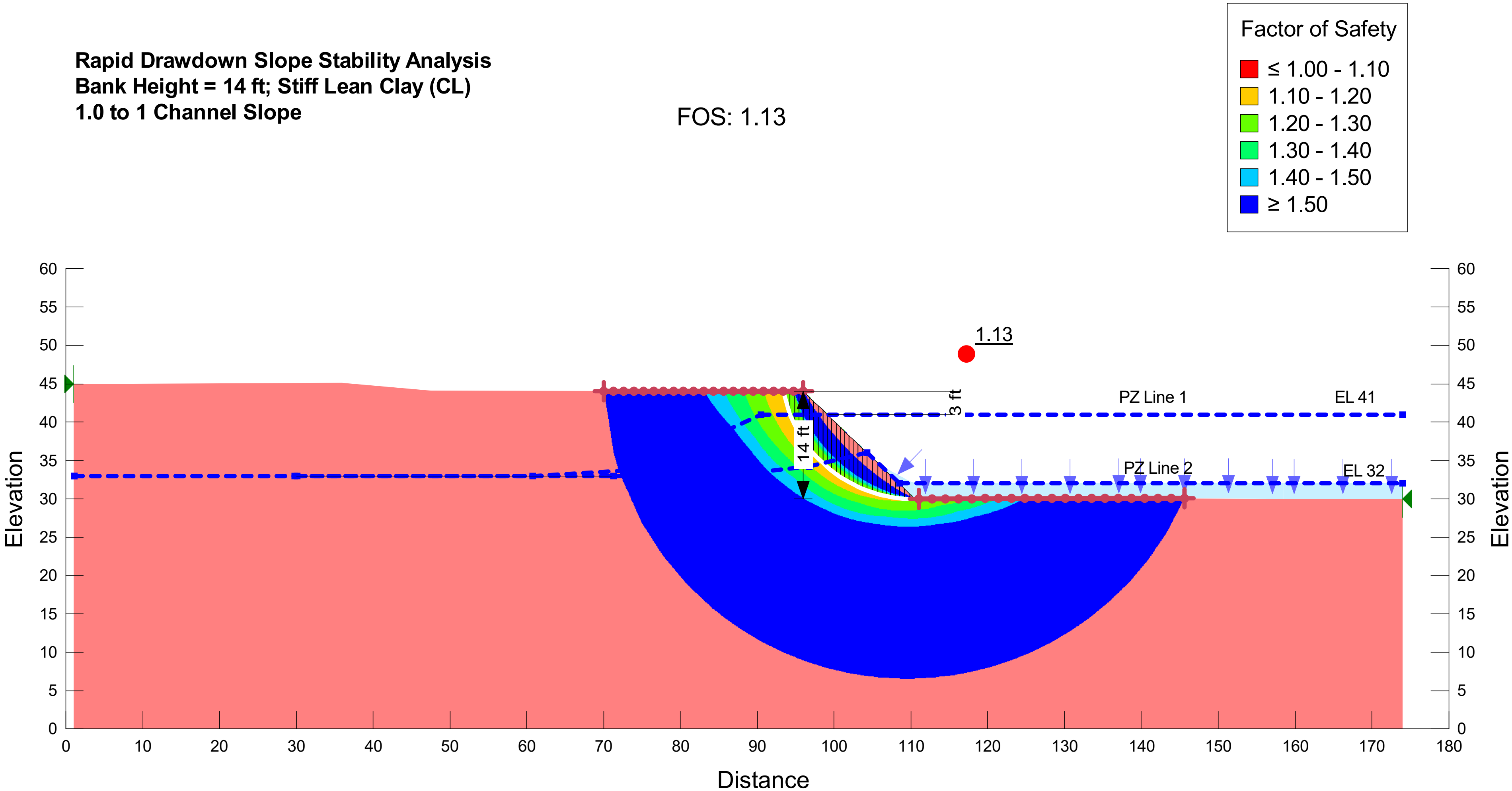
Color	Name	Unit Weight (pcf)	Effective Cohesion (psf)	Effective Friction Angle (°)	Cohesion R (psf)	Phi R (°)	Piezometric Surface	Piezometric Surface After Drawdown
	CH Stiff	120	100	26	2,000	0	1	2



Color	Name	Unit Weight (pcf)	Effective Cohesion (psf)	Effective Friction Angle (°)	Cohesion R (psf)	Phi R (°)	Piezometric Surface	Piezometric Surface After Drawdown
	CL Soft	120	100	24	500	0	1	2

Rapid Drawdown Slope Stability Analysis
Bank Height = 14 ft; Stiff Lean Clay (CL)
1.0 to 1 Channel Slope

FOS: 1.13



Color	Name	Unit Weight (pcf)	Effective Cohesion (psf)	Effective Friction Angle (°)	Cohesion R (psf)	Phi R (°)	Piezometric Surface	Piezometric Surface After Drawdown
	CL Stiff	120	100	30	2,000	0	1	2