Design Criteria and Technical Approach Memorandum

Feather River West Levee Improvements

Sutter Butte Flood Control Agency

Yuba City, California

DRAFT

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Contents

Figures

Tables

Appendices

Appendix A: Permeability Values Recommended by the Board of Senior Consultants for the Natomas Levee Improvement Project (January 31, 2009)

Introduction

HDR Engineering, Inc. (HDR) was awarded Contract No. xxyy on July xx, 2010. The project involves the development of the designs, plans, specifications, cost estimates, and related engineering documents for making the necessary flood improvements for 44 miles of the Feather River West Levee (FRWL), from the Sutter Bypass to Thermalito Afterbay through Sutter and Butte Counties. The 44 miles of the project have been divided into 7 segments (see Figure 1). All 7 segments will be designed to achieve FEMA accreditation for 100-year level of flood protection. In addition, the levees in Segments 1-6, and portions of Segment 7, will be designed to meet State of California requirements for 200-year urban flood protection.

This memorandum report documents the seepage and slope stability criteria to be utilized in evaluating the current integrity of the levees within the FRWL Project. It also presents the criteria and technical approaches to be used in developing remedial levee designs.

Project Description

Task Order 1 for this project was issued on July xx, 2010. The scope of work for Task Order 1 includes pre-design activities for levee improvements for the entire FRWL, as well as 30 percent design for levee improvements and relocations, a project description for environmental (CEQA/NEPA) documentation, and assembling a Conditional Letter of Map Revision (CLOMR) for FEMA. The necessary infrastructure modifications needed for the desired flood protection will be developed in detail as part of the pre-design effort. Preliminary estimates for Segments 1-4 (Levee Reaches 1-13) previously developed for the Preliminary Problem Identification Report and 10 Percent Design prepared by Peterson Brustad, Inc. (PBI, 2009) are summarized in Table 1 (note costs for Reach 13 included in estimates for other reaches).

Table 1. Preliminary Cost Estimates for Preferred Alternatives in Segments 1-4 (Reaches 1 through 13, from Peterson, Brustad, Inc., September 2009)

Reach	Levee Station	Length (ft.)	Preferred Alternative	Estimated Cost
1	3246+00 to 3297+00	5,100	Soil-bentonite slurry cutoff wall	$ 8,000,000
2	3297+00 to 3391+00	9,400	Soil-bentonite slurry cutoff wall	$ 17,500,000
3	3391+00 to 3415+00	2,400	Deep soil mixing slurry cutoff wall	$ 6,900,000
4	3415+00 to 3465+00	5,000	Soil-bentonite slurry cutoff wall	$ 9,200,000
5	3465+00 to 3541+00	7,600	Soil-bentonite slurry cutoff wall	$ 9,800,000
6	3541+00 to 3595+00	5,400	Soil-bentonite slurry cutoff wall – with ditch relocation	$ 8,800,000
7	3595+00 to 3615+00	2,000	Soil-bentonite slurry cutoff wall – with canal relocation	$ 5,700,000
8	3615+00 to 3745+00	13,000	Soil-bentonite slurry cutoff wall – with canal relocation	$ 15,800,000
9	3745+00 to 3982+00	23,700	Drained stability berm – with canal relocation	$ 32,400,000
10	3982+00 to 3991+00	900	Drained stability berm – with filling of pond	$ 1,300,000
11	3991+00 to 4457+00	46,600	Drained stability berm – with canal relocation	$ 39,500,000
12	4457+00 to 4519+00	6,200	Flatten landside slope to 5H:1V	$ 8,300,000
	Subtotal	127,300		$163,200,000

In addition to the preliminary cost estimates developed by PBI, supplemental preliminary cost estimates were also developed for Levee Segments 5, 6, and 7. The combined preliminary cost estimate for the FRWL Project was described as $250 million in a March 10, 2010 public meeting as shown in Table 2 below:

Table 2. Preliminary Cost Estimates for FRWL Project (from information presented at Sutter Butte Flood Control Agency Public Meeting, March 10, 2010)

Levee Segment	Length (miles)	Estimated Cost
1 - 4	24.1	$ 165,000,000
5	6.	$ 24,000,000
6	6.	$ 27,000,000
7	8.5	$ 34,000,000
Total	44.6	$ 250,000,000

Federal and State Guidance Documents

The federal and state guidance documents used in developing the criteria and preparing this memorandum report include:

1. "*Investigation of Underseepage and Its Control – Lower Mississippi River Levees*," Technical Memorandum No. 3-424, prepared for the President, Mississippi River Commission, Corps of Engineers, Waterways Experiment Station, United States Army Corps of Engineers, October 1956.
2. "*Seepage Analysis and Control for Dams*," Engineer Manual, EM 1110-2-1901, United States Army Corps of Engineers, 30 September 1986; 30 April 1993 (Change 1).
3. Code of Federal Regulations, "*Mapping of area protected by levee systems*," 44CFR65.10, Federal Emergency Management Agency, Department of Homeland Security, revised October 1, 2002.
4. "*Regulations of the Central Valley Flood Protection Board, Title 23. Waters*," California Code of Regulations, December 2009.
5. "*Settlement Analysis*", Engineer Manual, EM 1110-1-1904, USACE, 30 September 1990.
6. "*Laboratory Investigations and Testing*," Engineer Regulation, ER 1110-1-8100, United States Army Corps of Engineers, 31 December 1997.
7. "*Design and Construction of Levees*," Engineer Manual, EM 1110-2-1913, United States Army Corps of Engineers, 30 April 2000.
8. "*Geotechnical Investigation*," Engineer Manual, EM 1110-1-1804, United States Army Corps of Engineers, 1 January 2001.

9. "*Recommendations for Seepage Design Criteria, Evaluation and Design Practices,*" report prepared by the 2003 CESPK Levee Seepage Task Force for the Sacramento District, United States Army Corps of Engineers, 15 July 2003.

10. "*Slope Stability,*" Engineer Manual, EM 1110-2-1902, United States Army Corps of Engineers, 31 October 2003.

11. "*Design Guidance for Levee Underseepage,*" Engineer Technical Letter, ETL 1110-2-569, United States Army Corps of Engineers, 1 May 2005.

12. "*Guidelines for Landscape Planting and Vegetation Management at Levees, Floodwalls, Embankment Dams and Appurtenant Structures,*" Engineer Technical Letter, ETL 1110-2-571, United States Army Corps of Engineers, 10 April 2009.

13. "*Procedures for Drilling in Earth Embankments,*" Engineer Regulation, ER 1110-1-1807, United States Army Corps of Engineers, 1 March 2006.

14. "*Guidance Document for Geotechnical Analyses, Revision 6,*" prepared for Urban Levee Geotechnical Evaluations Program, Department of Water Resources, by URS Inc. in association with Fugro and GEI Consultants, March 2008.

15. "*Geotechnical Levee Practice,*" CESPK EQS Guidance Document (REFP10L0.DOC), Sacramento District, United States Army Corps of Engineers, 11 April 2008.

16. "*Interim Levee Design Criteria for Urban and Urbanizing Area State-Federal Project Levees,*" Fourth Draft, California Department of Water Resources, September xx, 2010.

Datum

The datum to be used for this project will be the 1988 North American Vertical Datum (NAVD88). Plans and specifications for construction work will employ this datum, as will geotechnical analyses and hydrologic/hydraulic information presented in various documents. Information developed using other datums will be corrected to the NAVD88 datum using appropriated corrections that have been reviewed and accepted by USACE.

Design Water Surfaces

Design Water Surface Elevation

The proposed design for the FRWL Project improvements will meet 100-year level of flood protection for all 7 segments, and 200-year level of flood protection for Segments 1 through 6, and most of Segment 7. The design water surface elevations (DWSE) for the FRWL Project for both the 100-year and 200-year water surfaces were developed by PBI using deterministic hydrologic and hydraulic analyses assuming conservative parameters. Risk and uncertainty analyses (R&U) were not completed for this project. The addition of up to 1 foot of elevation to account for the effects of climate change was not included in the development of the water surfaces (see PBI, xxx). Table 3 presents the DWSE values for both the 100-year and 200-year levels of flood protection.

Table 3. Design Water Surface Elevations (from Peterson, Brustad, Inc., xxxx yy, 2009)

Levee Station	100-year DWSE (NAVD88, ft.)	200-year DWSE (NAVD88, ft.)	1957 WSE (NAVD88, ft.)
3275+00	78.5	82.4	80.5
3579+00	82.0	84.8	85.5
3594+00	82.1	84.9	86.0
3645+00	83.0	85.5	86.5
3864+90	88.3	89.8	92.0
3986+10	93.7	94.8	97.0
4073+00	98.8	100.1	103.0
4123+00	102.0	102.8	106.0
4223+10	107.8	108.8	112.0
4243+06	108.7	109.7	112.5
4378+20	120.6	122.4	123.5
4443+10	123.1	124.6	126.0
4492+96	126.6	127.9	129.5

Hydraulic Top of Levee (HTOL) Water Surface Elevation

The State of California requires that seepage and slope stability for a 200-year level of flood protection be checked at a water surface higher than the design water surface. This is intended to ensure that the principal mode of failure is by overtopping, and that the levee does not fail by other mechanisms until the levee actually overtops. In conformance with the Department of Water Resources Interim Levee Design Criteria (DWR ILDC), Version 4, the HTOL water surface will be set at either the:

- Median 200-year water surface plus 3 feet,

or

- Median 500-year water surface,

whichever, is lower.

Technical Approach for Geotechnical Evaluations and Designs

There are already approximately 765 borehole and cone penetrometer test (CPT) soundings that have been completed for the FRWL Project. Consequently, most of the necessary geotechnical information has largely been acquired already. It is anticipated that 50 boreholes or CPT soundings will be completed for Task Order 1for the 30 percent design in order to fill in gaps in our understanding of the levee and its foundation. A minimum of 50 additional boreholes or CPT soundings are anticipated to be needed during the final design phase to help verify the adequacy of proposed designs.

There are also preliminary geotechnical evaluations previously completed for several sections along the FRWL Project by both Kleinfelder, Inc. and by URS, Inc.

The technical approach for evaluating seepage and slope stability for the FRWL Project will be as follows:

- Update previous geotechnical site characterizations along the FRWL Project.
- Evaluate previous geotechnical analyses and update with new layering and properties where appropriate.
- Perform through-levee seepage, underseepage, and slope stability analyses for different reaches and sub-reaches to evaluate levee integrity. Analyses will be based on critical conditions (e.g. thickest or deepest foundation aquifers, thinnest foundation blankets, steepest slopes, etc…). In some cases, analyses from one reach may be used to evaluate conditions in another reach if conditions (e.g. levee and foundation geometry, foundation layering, and geotechnical properties) are similar.
- Determine which levee reaches and sub-reaches can be shown to have 100-year and 200-year levels of flood protection with no new levee improvements.
- Identify seepage and slope stability deficiencies and their extents.
- Work with other members of design team to identify other potential deficiencies or issues including reaches susceptible to erosion, levee penetrations requiring relocations or modifications, canal/ditch relocations, and environmental and cultural issues.
- Complete Alternatives Analyses for each levee reach with identified deficiencies.
- Develop, or update, preferred alternatives for each levee reach found to be deficient.
- Complete 30 percent designs and cost estimates for updated preferred alternatives.

Evaluation and Design Criteria

Criteria to be used for the FRWL Project are based on published federal and state regulations and technical guidance documents. For levees to be accredited by FEMA, evidence must be provided that adequate design and operation and maintenance (O&M) systems are in place to provide reasonable assurance that protection from the base flood with a 1-percent annual chance of exceedance (i.e. 100-year flood) exists. These requirements are outlined in the Code of Federal Regulations (44CFR65.10).

California Code Regulations (CCR) Title 23 requirements for levees in the Central Valley have general provisions similar in intent to those in FEMA's 44CFR65.10. In 2007, California passed legislation (Senate Bill 5) that will require a 200-year level of flood protection as the minimum standard for urban areas in the California Central Valley by 2025; restrictions on development in a flood basin may occur if significant progress does not occur by 2015.

In general, USACE criteria will be followed for the design of levees based on the requirements of 44CFR65.10 as well as recent publications not cited in 44CFR65.10. This includes design criteria for levee geometry, seepage, slope stability, levee settlement, and levee construction materials as well as requirements for geotechnical site investigations, seepage analyses, slope stability analyses, and settlement analyses. Additionally, USACE criteria will be followed for the design of embankment erosion protection, interior drainage, and for the requirements of an O&M plan.

Because of varying requirements and recommendations in the published design standards, there are sometimes difficulties in interpreting the standards to establish the most appropriate design criteria. In regards to USACE published documents, including Engineer Manuals (EM), Engineer Regulation (ER), and Engineer Technical Letters (ETL), design criteria in the most recent publications supersede previous publications. Also, design criteria presented in USACE Sacramento District publications will be followed provided the criteria is at least as strict (i.e. conservative) as other USACE publications.

Design criteria were established for the following levee system components and are discussed in the following sections:

- Top of Levee (TOL) crown elevation
- General levee cross-sectional geometry
- Geotechnical criteria in regards to:
  - Underseepage and through seepage
  - Static slope stability
  - Liquefaction and seismic stability
  - Levee settlement
  - Levee embankment materials

Additionally, there are requirements in regards to activities or facilities on or near the levee embankment that include:

- Pipeline and conduit penetrations
- Penetration of utility poles and supports and other structures
- Levee vegetation and encroachments
- Canals, pipelines, and other structures adjacent to the levee toe

Additional design criteria are required for drainage and conveyance of surface water from the levee and adjacent roadways.

Top of Levee Crown Elevation

The TOL crown elevation is established to reduce the risk of overtopping by first determining the DWSE and then adding the required additional levee height in accordance with FEMA and State design guidance. The TOL will be established at the lower of the two levee crown hinge points, depending on crown slope for drainage. The design TOL elevation also includes an allowance for future levee and foundation settlement.

Levee Height

The levee DWSE plus an additional height for freeboard is required to establish the levee TOL to reduce the risk of overtopping. The various agencies and guidelines provide different recommendations for this additional height.

- Three feet of height for freeboard is added to the 100-year DWSE in accordance with 44CFR65.10. However, an additional 1 foot of freeboard is often required near bridge crossings and other constrictions;
- FEMA (i.e., 44CFR65.10) does not address a 200-year level of flood protection and an associated freeboard value;
- The draft DWR ILDC states that a minimum of 3 feet of height for freeboard is added to the 200-year DWSE. However, where necessary, it also requires larger heights to protect the levee against high winds and wave run-up.

For levee reaches which are required to meet the State of California's 200-year level of flood protection, the minimum freeboard will be 3 feet above the 200-year DWSE. For levee reaches which are required to only meet FEMA's 100-year level of flood protection, the minimum freeboard will be 3 feet above the 100-year DWSE. Additional freeboard will be incorporated, as needed, to address wave run-up, bridge crossings, and pipeline/utility crossings.

General Levee Cross-Sectional Geometry

The minimum levee cross section is based on a review of the following documents:

- USACE EM 1110-2-1913, dated April 30, 2000
- USACE ETL 1110-2-569, dated May 1, 2005
- USACE Sacramento District Geotechnical Levee Practice (GLP), dated April 11, 2008
- CVFPB CCR Title 23

The following minimum levee section was selected for the levee design options:

- Minimum levee crown width of 20 ft
- Waterside slope 3H:1V or flatter

- Landside slope 3H:1V or flatter for new levees, 2H:1V for existing or modified slopes provided they meet slope stability criteria at this steeper slope and that there have not been past performance problems

Geotechnical Criteria

Underseepage and Through Seepage

Levee embankment stability can be compromised if hydraulic exit gradients caused by relatively high underseepage pressures exceed allowable values. Excessive hydraulic exit gradients can result in the formation of sand boils, piping, and levee failure if left unrepaired. Similarly, seepage through the levee embankment can result in seepage breakouts on the landside levee slope and reduce levee slope stability or lead to piping failures.

The following USACE publications were used to evaluate underseepage and through seepage for the levee:

- USACE EM 1110-2-1913, dated April 30, 2000
- USACE ETL 1110-2-569, dated May 1, 2005
- USACE Sacramento District GLP, dated April 11, 2008
- USACE EM 1110-2-1901, dated April 30, 1993.

Based on these publications, the average hydraulic exit gradients must be equal to or less than the following values for water at the DWSE:

- Landside levee toe: ≤ 0.5
- Toe of seepage berm: ≤ 0.8
- Landside levee toe with seepage berm: ≤ 0.5
- Landside levee toe with relief wells: ≤ 0.5
- Bottom of empty ditch at landside toe: ≤ 0.5
- Bottom of empty ditch 150 ft or more from landside toe: ≤ 0.8
- For ditches between the landside toe and 150 ft from the landside toe, linearly interpolate between 0.5 and 0.8

The average exit gradients summarized above are based on the assumption that the saturated unit weights of the "in situ" landside blanket soils and seepage berm (if present) must be at or above 112 pounds per cubic foot. If the saturated unit weight of the landside blanket soils is less than 112 pounds per cubic foot, the allowable exit gradient would be reduced to achieve the required minimum factor of safety of 1.6 for the exit gradient. It is also suggested in the USACE Sacramento District GLP that the maximum exit gradient should be lowered as low as 0.3 at critical locations such as pump stations, sumps, swimming pools or areas difficult to flood fight.

When seepage berms are used to mitigate underseepage, the berm is sized such that the average hydraulic exit gradient at the landside toe of the berm is less than or equal to 0.8 for the DWSE. USACE recommends minimum berm dimensions if a seepage berm is required to obtain acceptable hydraulic exit gradients. These values are:

- Minimum berm width of four times the levee height (ETL 1110-2-569, USACE Sacramento District GLP, 2008)
- Minimum berm thickness of 5 ft at the levee toe (USACE Sacramento District GLP, 2008)
- Minimum berm thickness of 3 ft at the berm toe (USACE Sacramento District GLP, 2008)

The USACE also recommends a minimum berm slope of 2% if berm settlement can occur and 1.3% if post-construction settlement is not expected. For the minimum berm dimensions, the berm slope would be 2% (2 ft change in thickness over 100 ft width, assuming flat ideal topographic conditions).

With regards to the maximum seepage berm width, ETL 1110-2-569 states when the hydraulic gradient at the berm toe exceeds 0.8 for a 300 to 400 ft wide seepage berm (i.e. factor of safety less than 1.0):

"Great caution and good engineering judgment should be used for recommended seepage remediation in these reaches."

USACE Sacramento District GLP states the maximum seepage berm widths are typically 300 ft, and the draft DWR ILDC states that achieving the required hydraulic exit gradients is required for berm widths less than 300 ft. Based on recent experience in the region, it is anticipated that most berm widths designed for the FRWL Project will be no wider than 300 feet.

The DWR ILDC also requires for the 200-year level of flood protection that the exit gradient be checked at the berm toe for the HTOL WSE. It requires that the underseepage factor of safety at the toe of the berm does not decrease more than 20 percent from that measured for the DWSE to the HTOL WSE, if the berm is less than 100 feet in width. If the unit weight of the landside blanket soil is less than 110 pcf, then the decrease in factor of safety has to be less than 10 percent. For berms more than 100 feet in width, good engineering judgment is recommended.

Cutoff walls will have a minimum thickness of 36 inches for the conventional method, 32 inches for the Deep Soil Mix (DSM) and 27.6 inches for the Trench Cutting and Remixing (TRD), and will generally extend at least 5 ft into the low permeability substrata. The designed permeability objective of the wall shall be a maximum 1×10^{-6} cm/sec.

Seepage Analyses

Seepage and Underseepage analyses will be conducted using State-of-Practice approaches accepted by both the USACE and by the State of California:

- Past performance information of the FRWL Project levees that is readily available will be reviewed.
- Readily available geomorphology reports and historical maps and photographs will be reviewed to gain insight to the foundation history.
- Any pertinent and readily available data recently produced by the California Department of Water Resources will be reviewed (e.g. Helicopter Electromagnetic Surveys).
- Any readily available previous seepage evaluations completed by the Corps or State in the vicinity of the sites will be reviewed.
- Using the readily available information and applying engineering judgment, seepage finite element models will be developed. Each model will be developed to represent the most critical conditions rather than typical ones at each location or reach.
- The finite element computer program to model seepage/underseepage will be SEEP/W, version 7.14. The boundary conditions for the models will be as follows:
  - Fixed-head boundary conditions set to the river stage will be used along the boundary nodes of the waterside levee slope, river bottom, and the waterside vertical edge of the model. This is a conservative assumption to account for potential scour/erosion of the waterside slope and surface blanket material.
  - Nodes along the bottom of the model will be set to have no flow condition, corresponding to the presence of a low permeability aquaclude at this elevation.
  - Nodes on the landside vertical edge will be set to have no flow conditions. This conservative assumption is being assumed to account for the potential lack of continuity of layers/deposits beyond the immediate landside area of the levee. However, this boundary will be set far away from the levee itself.
  - Nodes on the landside levee slope and the landside ground surface will be modeled as potential seepage surfaces.
- The SEEP/W model will extend landward approximately 2,000 feet to assure that boundary elements are not adversely impacting the analysis. If topographic information is not available out to 2,000 feet, engineering judgment will be used to extend the model – in some cases, the ground surface and layering may simply extend horizontally beyond the limits of the available information.
- On the waterside, the model will extend to the middle of the river.
- The bottom of the model will extend down to include a relatively impervious soil layer (s). This bottom boundary will depend upon what the available geotechnical information at each site reveals with respect to soil layering and will be established by engineering judgment.

- For some models, sensitivity studies with variable model lengths and boundary conditions will be conducted to verify assumptions and assure that model limits are not impacting the model results.
- Any ditches found at the sites will be modeled as empty.
- Soil parameters for the seepage models such as permeabilities will be developed after reviewing the available soil data, including laboratory test results and correlations between classification test results and permeabilities. The permeability values recommended by the Board of Senior Consultants for the Natomas Levee Improvement Project (see Appendix A) will be considered for use in the initial seepage analyses. Where data is readily available, permeability values will also be estimated based on the Kozeny-Carmen Equation, and permeability values will be selected after comparing these estimates to those recommended for the Natomas Basin.
- For each site analyzed, SEEP/W results showing seepage equipotentials and gradients will be plotted. In addition, the average vertical gradients across the landside blanket layer at the landside levee toe and, if present, the landside berm toe will be calculated and presented. The properties of the soil layers will also be shown for each summary plot.
- Seepage results from SEEP/W will be reviewed for reasonableness. In addition, representative SEEP/W analyses for the DWSE will be checked by performing an analysis using the Corps blanket theory (EM 1110-2-1913 – Appendix B, TM 3-424). The Blanket Theory analyses will be based on the same stratigraphy and properties as will the SEEP/W analyses. Seepage analyses found to be questionable will be examined and sensitivity analyses that vary model dimensions and properties will be carried out to resolve any calibration check issues.
- Intermediate consultation with USACE and State of California staff will be made at different periods of the analyses, both before and after the analyses are conducted. An External Independent Review Panel, or Board of Senior Consultants, will also be retained by SBFCA to review the analyses and adequacy of the proposed levee improvements. Consultation with this Panel, or Board, will also be conducted on a regular basis. As part of the Quality Control Plan, all external comments will be responded to, resolved, and closed.
- The results of the seepage analyses will be documented in written form and will also include the methods and soil parameters used in the analyses, along with comparisons between the computed results and the maximum allowable exit gradients or minimum factors of safety.

Through-Levee Seepage Exiting on Landside Levee Slope

Levees which are shown to have a phreatic line for either the DWSE or the HTOL WSE which emerges on the landside levee slope must be evaluated for piping seepage. Levees with erodible soils that may experience this condition will require remediation to prevent unraveling and progressive slope failure.

Static Slope Stability

Levee slope stability analyses will be performed in general accordance with EM 1110-2-1913 for free water surface at the DWSE and at the HTOL WSE. The required minimum factors of safety presented in EM 1110-2-1913 for the DWSE are:

- End of Construction 1.3
- Steady State 1.4
- Rapid Drawdown 1.0 to 1.2 (only applicable to waterside slope)

Steady state seepage is anticipated to be the controlling load case for slope stability, particularly on the landside slope. The draft DWR ILDC for 200-year level of protection uses the same factor of safety for steady state seepage with the exception of the analysis at the HTOL WSE, where the factor of safety is reduced to 1.2.

In some cases where it can be conclusively shown that the levee embankment is composed of impervious soils, a lower phreatic line may be justified and used in the analyses and designs per DWR ILDC and USACE allowances.

Slope Stability Analyses

Slope Stability Analyses will be conducted using State-of-Practice approaches accepted by both the USACE and by the State of California:

- The same general stratigraphy and models used for the seepage/underseepage analyses will be used.
- Computer program SLOPE/W version 7.14 will be used for the slope stability calculations. Pore pressures computed by SEEP/W will be imported into SLOPE/W for use in the analyses.
- The method of analysis will be Spencer's Method, a limit equilibrium method of analysis which assumes that a potential circular sliding surface can be modeled by subdividing the mass above the sliding surface into a number of vertical slices. Moments are calculated for a hypothetical circle center and an iterative process is used to arrive at moment equilibrium. In Spencer's Method, it is assumed that the interslice forces between all slices in the potential sliding mass are parallel (i.e. all interslice forces have the same inclination). If engineering judgment concludes that it is appropriate, non-circular sliding surfaces will also be considered.
- The steady-state seepage slope stability models will employ effective shear strengths for the different soil layers. Effective shear strengths will be selected after reviewing the available soils data, including laboratory test results and correlations between

classification test results and effective shear strengths. Comparisons will also be made to parameters selected by the USACE and consulting firms in previous analyses. Effective cohesion values may be used if justified by available information, but values will be no higher than 200 psf for clayey soils and 50 psf for sandy soils.

- The rapid drawdown analyses will commonly be performed using the following steps:
  - In addition to effective shear strengths, undrained shear strength parameters will also need to be estimated. These also will be based on previous laboratory test results, correlations between classification test results and undrained shear strength, and values used in previous analyses.
  - Computer program SEEP/W will be used to calculate excess pore pressures that are then exported into either UTEXAS4 or SLOPE/W for slope stability calculations. The pre-drawdown water surface will be the DWSE. The drawn-down water elevation will be set equal to the "typical" winter water level.
  - In many cases, the three-stage method developed by Duncan, Wright, and Wong (1990) will be used for the analysis. This is comparable to those used recommended by both the USACE (EM 1110-2-1913) and CDWR procedures. In this method, the calculations proceed in three stages. The first stage uses effective shear strengths and is used to calculate the effective normal and shear stresses prior to drawdown. The second stage employs the drawn-down water surface and pore pressures together with undrained shear strengths based on the effective stresses calculated during the first stage. A third stage is done by using effective shear strengths and zero pore pressures.

  In some instances, simplified procedures may be used in conjunction with, or instead of, the above approach.
- The results of the SLOPE/W analyses will be reviewed for reasonableness. In addition, selected analyses will be checked by hand-calculations or by another computer program, UTEXAS4. Slope stability analyses found to be questionable will be examined and sensitivity analyses that vary soil strengths will be carried out to resolve any calibration check issues.
- Intermediate consultation with USACE and State of California staff, together with the External Independent Review Panel, will be made at different periods of the analyses, both before and after the analyses are conducted. Again, as part of the Quality Control Plan, all external comments will be responded to, resolved, and closed by the end of the final design phase.
- The results of the slope stability analyses shall be documented in written form that will also include the methods and soil parameters used in the analyses, along with comparisons between the computed results and the required minimum factors of safety.

Earthquake Loading

In regards to earthquake loading, EM 1110-2-1913 states the following:

"Earthquake loadings are not normally considered in analyzing the stability of levees because of the low probability of earthquake coinciding with periods of high water. Levees constructed of loose cohesionless materials or founded on loose cohesionless materials are particularly susceptible to failure due to liquefaction during earthquakes. Depending on the severity of the expected earthquake and the importance of the levee, seismic analyses to determine liquefaction susceptibility may be required."

The following statements are made in the draft DWR ILDC:

- An analysis of seismic vulnerability of the levee system from 200-year ground motions is required, using typical summer and winter water surface elevations.
- If seismic damage is expected after all 200-year flood improvements are in place, a post-earthquake remediation plan will be required for quickly restoring the levee system's grade and dimensions sufficient for protection against the 10-year flood, with 3 feet of freeboard, or higher as needed for 10-year wave run-up.
- To the extent that seismic damage to the levee system would be so significant and widespread that it would be infeasible to restore 10-year protection within a few months, seismic strengthening may be required for 200-year certification.

Neither USACE nor DWR provide specific design criteria to perform seismic analyses other than DWR stating that a 200-year ground motion should be used. Additionally, there are no other established guidelines for the seismic evaluation of levees. We propose the following:

- Establish ground motions and dominant moment magnitude through disaggregation for an earthquake with a 200-year recurrence interval
- The groundwater level was taken as the nominal river stages during both summer and winter months
- Perform liquefaction analyses and determine potentially liquefiable layers
- If the factor of safety (FOS) against liquefaction is less than 1.0, perform pseudodynamic and post-earthquake static slope stability analyses using residual shear strengths for the liquefiable layers
    - If the post-earthquake slope stability FOS is less than 1.0, the levee cross-section will be considered to be vulnerable to flow failure and large deformations (Case A)
    - If the post-earthquake slope stability FOS is greater than 1.0, a yield acceleration from the pseudodynamic static slope stability analyses will be completed and earthquake-induced deformations will be estimated (Case B)

- If no liquefaction occurred, some limited earthquake-induced volumetric settlement and limited shear displacements could occur and will be estimated (Case C)

Using the results of the seismic and dynamic slope stability analyses, a general level of earthquake-induced deformation and damage will be estimated for the 44 miles of levees in the FRWL Project. This estimate will be used to develop an Emergency Action Plan to fulfill the requirements of the DWR ILDC for 200-year level of flood protection.

Levee Foundation Settlement

Foundation settlement due to levee construction will be evaluated and accounted for when establishing the TOL elevation. The levee design TOL will be increased to account for the calculated post-construction consolidation settlement.

Levee Embankment Material

The USACE Sacramento District GLP and State of California Title 23 provide requirements for levee embankment fill material; EM 1110-2-1913 does not provide specific requirements for levee fill material. For most new or adjacent levee sections, we propose the following initial objectives:

- Levee Fill
  - Liquid Limit (LL) is less than or equal to 45 (may be extended up to 55 with justification and approval from USACE and CVFPB)
  - Plasticity Index (PI) is greater than or equal to 8 and is less than 40
  - Fines content (Passing no. 200 sieve) is greater than or equal to 30%
- Seepage Berm and General Purpose Fill (Random Fill)
  - All suitable borrow material

For these materials, the maximum particle size is 2 inches.

Levee embankment material will be compacted to 97% of the maximum density per American Society of Testing and Materials (ASTM) D 698, with a moisture content between -1 and +3% of optimum. The change from moisture content values of -2 to +2% presented in the GLP (2008) was previously agreed upon with USACE Sacramento District. Seepage berm fills will be compacted to 90% of the maximum density per ASTM D 698.

Penetrations and Encroachments

Penetrations and encroachments into the levee prism are generally not allowed without approval by USACE. The levee prism is defined as a surface with a top elevation equal to the design TOL and design slope projections (no steeper than 3H:1V for new slopes) that extend downward on both the waterside and landside slopes with a minimum crown width of 20 feet.

Pipes and Conduits

All existing pipes and conduits beneath the levee prism or within 10 ft of the toe of the levee or seepage berm will be removed and replaced as necessary to meet the following criteria:

- Pressure pipes/conduits crossing beneath the levee crown must be above the 200-year design water surface elevation and outside of the landside and waterside slope of the levee prism.
- These pipes must be equipped with a positive cutoff valve waterside of the levee crown.

Utility Poles and Supports

Utility poles and supports that interfere with the proposed levee construction will be relocated prior to levee construction. In general, utility pole foundations are not allowed to penetrate the levee prism unless approved by the USACE. Utility poles and supports may penetrate seepage berms with a permanent reinforced concrete foundation installed through the berm and into the foundation.

Levee Vegetation

USACE requires a “vegetation-free zone” as explained in ETL 1110-2-571 (see Figure 2). The vegetation-free zone contains the levee crown, the side slopes and a 15 foot setback from the landside and waterside toes. Where new levees or new levee slopes will be constructed, only native grasses will be planted on the levee slopes and any seepage berms. For unmodified levee slopes, existing trees and other woody vegetation would either be removed and mitigated in compliance to USACE requirements, or SBFCA will seek a variance from the USACE to retain the vegetation (note: variance processes and criteria are currently pending), and develop a life-cycle management plan to manage the vegetation over time following criteria currently being established by the DWR ILDC.

Other Encroachments

To be determined with Sutter Butte Flood Control Agency and external agencies (USACE, CVFPB, DWR).

Canals and Pipelines Adjacent to Levee

To be determined with Sutter Butte Flood Control Agency and external agencies (USACE, CVFPB, DWR).

Figure 1: Levee Segments for the Feather River West Levee Project (from xxx, 2009)

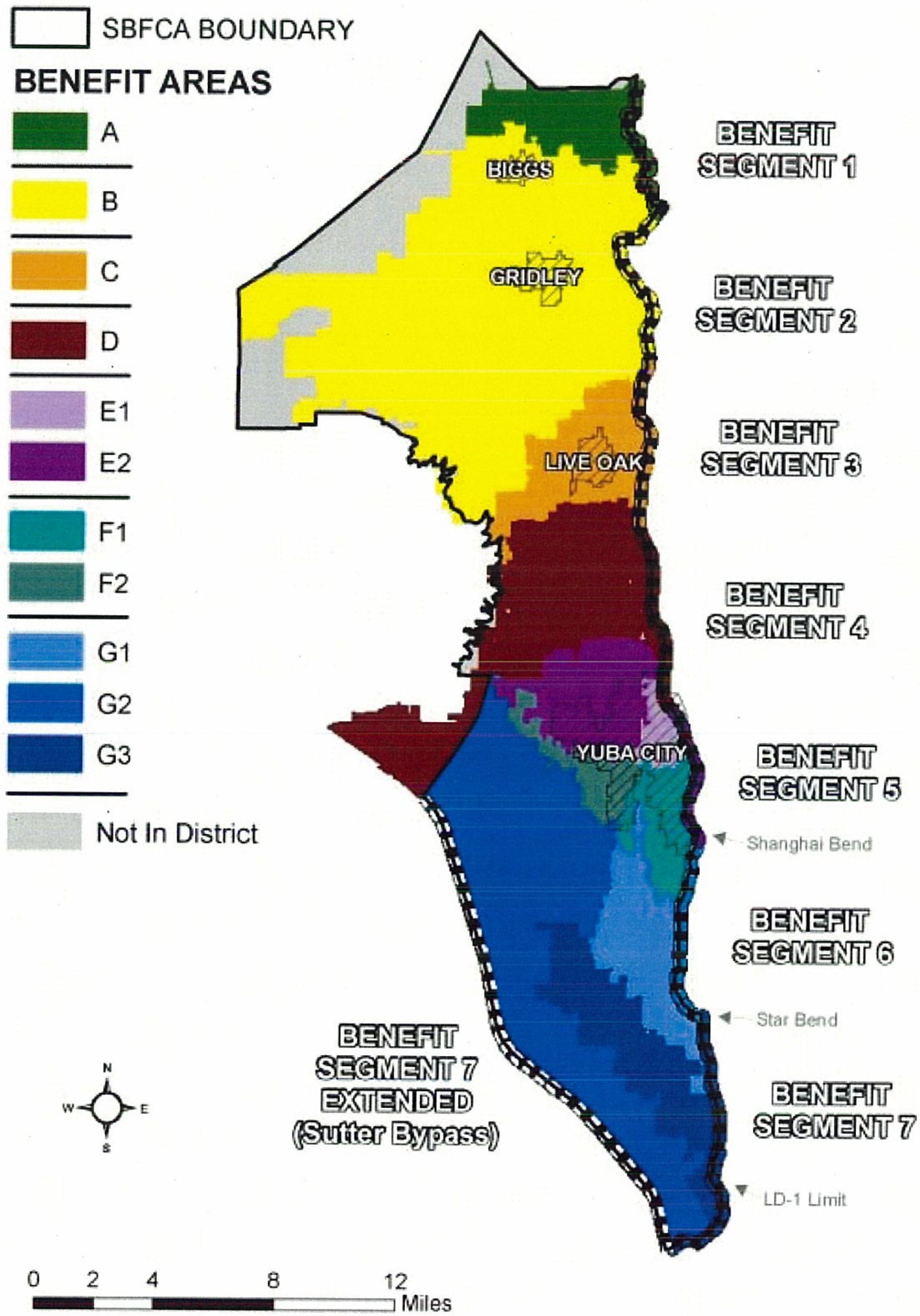
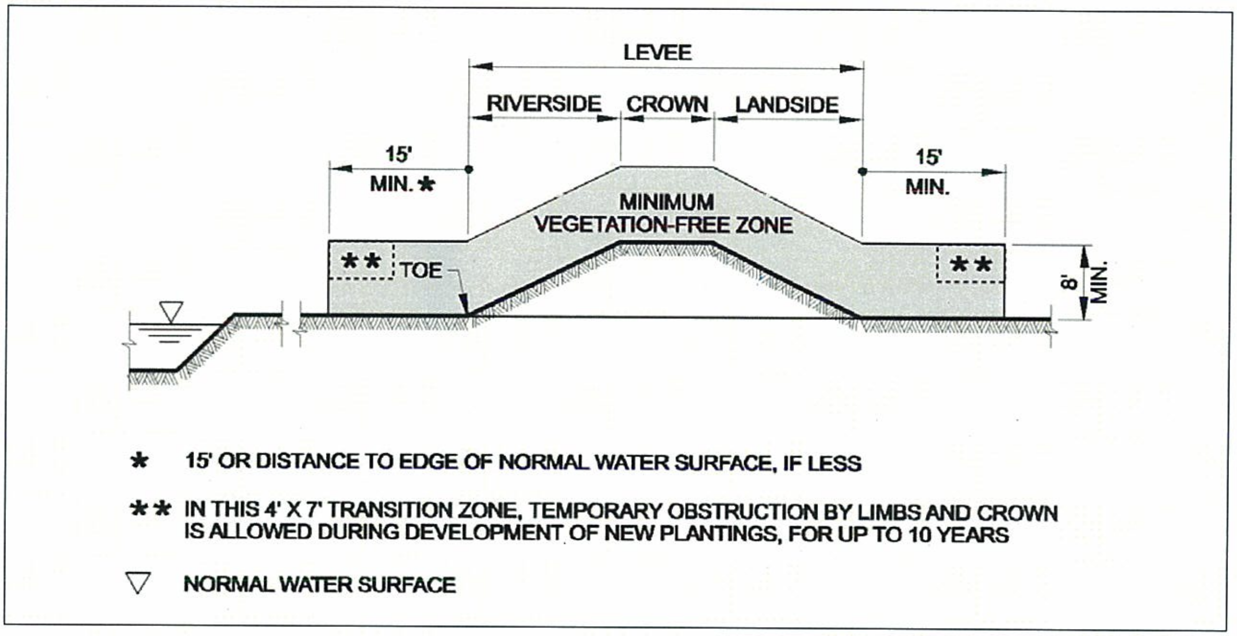


Figure 2: Minimum Vegetation-Free Zones for Federal Levees
(from Corps of Engineers, ETL 1110-2-571, April 10, 2009)



APPENDIX A: Permeability Values Recommended by the Board of Senior Consultants for the Natomas Levee Improvement Project (January 31, 2009)

Table A-1: Permeability Values Recommended by the Board of Senior Consultants for the Natomas Levee Improvement Project (January 31, 2010)

Material Type	Soil Description	K_h (cm/sec)	K_v/K_h	K_v (cm/sec)	Layer Color
Slurry Wall	SCB or CB	1×10^{-6}	1	1×10^{-6}	Violet
	SB	1×10^{-7}	1	1×10^{-7}	
Clay (CL, CH)	New Compacted Clay Levee	1×10^{-6}	0.25*	2.5×10^{-7}	Indigo
	New Compacted Clay Berm	1×10^{-6}	0.25*	2.5×10^{-7}	
	Clay Layer over 20 feet below ground surface	1×10^{-6}	0.25*	2.5×10^{-7}	
	Clay Blanket	1×10^{-5}	0.25*	2.5×10^{-6}	
Silt (ML, MH)	Silt or Plastic Silt 80 – 100% fines content, or >50% fines content and PI > 4	1×10^{-5}	0.25*	2.5×10^{-6}	Blue
	Sandy Silt 50 – 79% fines content	3×10^{-5}	0.25*	7.5×10^{-6}	
Clayey Sand to Sand (SC, SP-SC, SW-SC, SP, SW)	30 – 49% fines content	3×10^{-6}	0.25*	7.5×10^{-7}	Pink
	13 – 29% fines content	3×10^{-5}	0.25*	7.5×10^{-6}	
	8 - 12% fines content	3×10^{-4}	0.25*	7.5×10^{-5}	
	3 - 7% fines content	3×10^{-3}	0.25*	7.5×10^{-4}	Yellow
	0 - 2% fines content	1×10^{-2}	0.25*	2.5×10^{-3}	
Silty Sand to Sand (SM, SP-SM, SW-SM, SP, SW)	30 – 49% fines content	1×10^{-4}	0.25*	2.5×10^{-5}	Green
	13 – 29% fines content	3×10^{-4}	0.25*	7.5×10^{-5}	
	8 - 12% fines content	1×10^{-3}	0.25*	2.5×10^{-4}	Yellow
	3 - 7% fines content	3×10^{-3}	0.25*	7.5×10^{-4}	
	0 - 2% fines content	1×10^{-2}	0.25*	2.5×10^{-3}	
Clayey Gravel to Sandy Gravel (GC, GP-GC, GW-GC, GP, GW)	30 – 49% fines content	3×10^{-6}	0.25*	7.5×10^{-7}	Pink
	13 – 29% fines content	3×10^{-5}	0.25*	7.5×10^{-6}	
	8 - 12% fines content	3×10^{-4}	0.25*	7.5×10^{-5}	
	0 - 7% fines content	1×10^{-2}	0.25*	2.5×10^{-3}	Yellow
Silty Gravel to Sandy Gravel (GM, GP-GM, GW-GM, GP, GW)	30 – 49% fines content	3×10^{-5}	0.25*	7.5×10^{-6}	Orange
	13 – 29% fines content	2×10^{-4}	0.25*	5.0×10^{-5}	
	8 - 12% fines content	1×10^{-3}	0.25*	2.5×10^{-4}	Yellow
	0 - 7% fines content	1×10^{-2}	0.25*	2.5×10^{-3}	

* Note: The K_v/K_h ratio of 0.25 is intended as an initial value to be considered for seepage analyses. Depending upon the stratifications of the deposits, other ratios may be more appropriate. For example, a K_v/K_h value of 0.5 to 1.0 may be appropriate for clean sandy or gravelly deposits that do not have layers or lenses containing fine material. On the other hand, K_v/K_h values approaching 0.1 may be appropriate for highly stratified or lenticular deposits.