TECHNICAL MEMORANDUM

SLOPE STABILITY FOR INTERMITTENTLY LOADED LEVEES
ULOP GEOTECHNICAL EVALUATION
STAR BEND SETBACK LEVEE

Sutter County, California

Prepared by:

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May 2016

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BCI File No. 3012.X
July 12, 2016

Mr. Jay Punia
Wood Rodgers, Inc.
3301 C Street, Bldg. 100-B
Sacramento, CA 95816

Subject: **Technical Memorandum**
Slope Stability for Intermittently Loaded Levees
ULOP Geotechnical Evaluation
Star Bend Setback Levee
Sutter County, California

Dear Mr. Punia,

Blackburn Consulting (BCI) prepared this Technical Memorandum (TM) in accordance with our Subconsultant Agreement for the Star Bend ULOP Geotechnical Evaluation, effective April 1, 2016. This TM provides our slope stability analyses for intermittently loaded levees for the Star Bend Setback Levee.

Please contact us if you have questions or require additional information.

Sincerely,

BLACKBURN CONSULTING

Morgan Wright, P.E.
Project Engineer

Robert B. Lokteff, P.E., G.E.
Principal Geotechnical Engineer

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SUTTER COUNTY, CALIFORNIA

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1. PURPOSE

Blackburn Consulting (BCI) prepared this Technical Memorandum (TM) for Wood Rodgers, Inc. (WR) to support the Star Bend Setback Levee Urban Level of Flood Protection (ULOP) finding located in Sutter County, California. This TM provides analysis to verify and document that the Star Bend Setback levee meets slope stability criteria outlined in the May 2012 Urban Levee Design Criteria (ULDC) Section 7.4.

A Compliance Statement by the registered professional engineer in responsible charge of this work is provided in Attachment A.

2. SCOPE OF SERVICES

BCI performed the following to prepare this TM:

- Reviewed the Star Bend Setback Levee construction documents.
- Reviewed our 2006 BCI Star Bend Setback Levee slope stability analysis.
- Reviewed our 2006 Geotechnical Report and the 2007 Addendum No. 1 to Geotechnical Report subsurface explorations and laboratory test data.
- Prepared two representative subsurface cross-sections for slope stability analysis based on information from the construction documents, the 2006 Geotechnical Report and 2007 Addendum No. 1 to Geotechnical Report, current surface profile data provided by WR, and water surface elevations provided by Peterson Brustad, Inc. (PBI).
- Performed steady-state landside slope stability analysis and waterside rapid drawdown slope stability analysis at the two cross-sections in accordance with the 2012 ULDC.

3. PROJECT DESCRIPTION

BCI prepared the Star Bend Setback Levee 2006 Geotechnical Report and 2007 Addendum No. 1 to Geotechnical Report in accordance with the US Army Corps of Engineers (USACE) design criteria available at the date of the design. The design included a soil-bentonite (SB) slurry cutoff wall to mitigate underseepage deficiencies associated with a relatively impervious near-surface clay/silt "blanket" and underlying sand aquifer. Nordic Industries completed construction of the setback levee and cutoff wall in 2009. BCI provided geotechnical engineering support during construction.

The levee is approximately 20 to 25 feet tall with 3:1 (horizontal to vertical) waterside and landside side slopes, and a levee crest width of approximately 20 feet. The total length of the setback levee is approximately 3,300 feet. The levee embankment soil met the USACE criteria for compaction, moisture content, Plasticity Index, Liquid Limit and fines content. The SB slurry cutoff wall depth ranges from approximately 42 to 65 feet. The wall extends through the sand aquifer and terminates in a sandy clay/elastic silt layer underlying the aquifer.

We performed slope stability analysis for the 2006-2007 Star Bend Setback Levee design using the 1957 Water Surface Elevation (WSE). Current ULDC requires slope stability analysis using the 1) 200-yr-flood WSE plus additional loading to account for climate change, potential hydrologic/hydraulic model variations, or sea-level rise; and 2) Hydraulic Top of Levee (HTOL). This TM provides slope stability analysis using the WSEs required in the ULDC.

A Vicinity Map for the Star Bend Setback Levee is included in Figure 1. A Site Plan showing subsurface explorations is included in Figure 2. A Surficial Geology Map for the Star Bend Setback Levee area is included in Figure 3. A typical cross-section detail from the 2010 as-built plans is included in Figure 4.

4. DOCUMENTATION OF ULDC COMPLIANCE

This section contains our evaluation of the Star Bend Setback Levee with respect its ability to provide an urban level of flood protection meeting the ULDC Slope Stability Criteria for Intermittently Loaded Levees.

4.1 Cross-Section Development

We conducted our Star Bend Setback Levee slope stability evaluation using cross-sections we developed for underseepage evaluation at Sta. 20+46.18 and Sta. 39+46.18. For slope stability analysis, we assumed the setback levee material properties and geometry are generally consistent along the entire alignment.

See our concurrent Underseepage Analysis for Intermittently Loaded Levees Technical Memorandum (May 2016) for information on how we developed the cross-sections and subsurface characterization profiles used in this analysis. See Appendix C for geologic profiles corresponding to the project site.

We present the cross-section for Sta. 20+46.18 including explorations and subsurface characterization in Figure 4, and the cross-section for Sta. 39+46.18 including explorations and subsurface characterization in Figure 5. Boring logs and CPT plots we used to develop the cross-sections are included in Appendix A. Relevant laboratory test results are included in Appendix B.

4.2 Water Surface Elevations

Table 1 presents the water surface elevation (WSEs) and rapid drawdown (RDD) conditions considered for this analysis.

WR provided the 200-year-flood and 500-year-flood WSEs as determined by PBI for the Feather River West Levee. At the direction of WR, we added 1 foot to the 200-year WSE to account for climate change, potential hydrologic/hydraulic model variations, or sea-level rise. For the HTOL underseepage analyses, we used the lower of the 200-year-flood WSE + 3' and 500-year-flood WSE as specified in the ULDC.

The URS approach for Rapid Drawdown Analysis Technical Memorandum (December 2011) provided Feather River West Levee rapid drawdown analysis and water level drop recommendations. URS identifies that a 200-year flood is likely a short lasting high stage event. They based their recommendations for water surface drop and average WSEs from available hydrographs along the Feather River West Levee. For this RDD analysis, we used the DWSE condition with a 26-foot-drop level consistent with the December 2011 URS TM.

Table 1: Water Surface Conditions Used in This Slope Stability Analysis

Cross-Section	**HEC-RAS SBFCA/ FRWL Station**	**DWSE** (NAVD 88)	**HTOL** (NAVD 88)		**RDD**
		200-yr. + 1' (feet)	500-yr. WSE(feet)	200-yr. + 3' (feet)	Drop Level (feet)
Station 20+46.18	RM 18.30	67.20	70.74	69.20	26.0
Station 39+46.18	RM 17.86	66.09	69.49	68.09	26.0

4.3 Strength Parameter Selection

To determine strength parameters, we compared the 2006 Geotechnical Report and our 2007 Addendum No. 1 material properties and laboratory test results with SBFCA FRWL evaluations, ULE Guidance Document and the Star Bend Setback Levee Construction Completion Report. A tabulated comparison of these strength parameters is included in Appendix D.

We present our recommended material strength parameters in Table 2 followed by the parameter selection rationale.

Table 2: Strength Parameters Used in This Slope Stability Analysis

USCS Designation	**Soil Description**	**Unit Weight**	**ϕ' (deg)**	**c' (psf)**	**ϕ^{total} (deg)**	**c^{total} (psf)**
(1) SB Cutoff Wall	Soil bentonite cutoff wall	100	0	300	0	300
(2) CL	Newly compacted clay levee fill	130	33	100	15	100

Table 2: Strength Parameters Used in This Slope Stability Analysis							
USCS Designation		**Soil Description**	**Unit Weight**	**ϕ' (deg)**	**c' (psf)**	**ϕ^{total} (deg)**	**c^{total} (psf)**
(3) CL		Deeper clay	115	31	100	17	150
(4) CL/ML		Soft or desiccated clay/silt blanket, upper layers	120	31	75	18	150
(5) CL/MH		Sandy clay/plastic silt	125	31	75	18	150
(6) SP		Poorly-graded sand (Less than 5% fines)	120	36	0	---	---
(7) SP-SM		Poorly-graded sand with silt (5% - 12% fines)	120	35	0	---	---
(8) SM		Silty sand with variable percent fines	120	33	0	---	---

<u>Strength Parameter Selection Rationale</u>

- *SB Cutoff Wall:* We recommend a 0° effective and total friction angle and 300 psf effective and total cohesion for the SB slurry wall strength parameters consistent with the ULE Guidance document and the previous SBFCA FRWL evaluations.
- *Mechanically compacted levee fill (CL):* Construction records show that the levee fill consists of lean clay, silt, sandy lean clay, clayey sand, and sandy silt compacted to an average 102% relative compaction based on ASTM D 698. The records also indicate a Liquid Limit (LL) range from 22 to 45 with an average of 31, a Plasticity Index (PI) range from 7 to 29 with an average of 14, and a fines content (% Fines) range from 22% to 94% with an average of 73%.

  We performed consolidated, undrained compressive strength tests on remolded samples from borrow sites as part of the 2006-2007 Star Bend Setback Levee design. One sample, B1-06 Bulk #1 (LL = 38, PI = 13, % Fines = 75%), had similar index properties to the material used in the Star Bend levee construction and strength values similar to those previously used in the SBFCA FRWL levee evaluations. We recommend an effective friction angle of 33°, an effective cohesion of 100 psf, a total friction angle of 15°, and a total cohesion of 100 psf, consistent with the triaxial test results.
- *Deeper clay (CL):* Using subsurface explorations deeper than 50 feet, we identified a stiff high plasticity soil. We recommend an effective friction angle of 31°, an effective cohesion of 100 psf, a total friction angle of 17°, and a total cohesion of 150 psf. These strength values are similar to those previously used in the SBFCA FRWL levee

evaluations and are bracketed by the recommended ULE Guidance Document design strength values.

- *Soft or desiccated clay/silt blanket (CL/ML):* Existing borings and test pits indicate an approximately 10-foot-thick clay and silt blanket. We recommend an effective friction angle of 31°, an effective cohesion of 75 psf, a total friction angle of 18°, and a total cohesion of 150 psf. These strength values are similar to those previously used in the SBFCA FRWL levee evaluations and are bracketed by the recommended ULE Guidance Document design strength values.
- *Sandy clay/elastic silt (CL/MH):* Existing subsurface explorations indicate a stiff sandy clay or elastic silt layer. We recommend an effective friction angle of 31°, an effective cohesion of 75 psf, a total friction angle of 18°, and a total cohesion of 150 psf. These strength values are similar to those previously used in the SBFCA FRWL levee evaluations and are bracketed by the recommended ULE Guidance Document design strength values.
- *Poorly-graded sand (SP):* We identified material as relatively clean poorly-graded sand with apparent density varying from very loose to dense. For this analysis, we used an effective friction angle of 36°. This effective friction angle is similar to friction angles for clean, poorly-graded sands used in the previous SBFCA FRWL levee evaluations.
- *Poorly-graded sand with silt (SP-SM):* We identified material below the relatively impermeable cutoff layer as medium dense to dense poorly-graded sand with few fines. We recommend an effective friction angle of 35°, similar to values used in the SBFCA FRWL levee evaluations.
- *Silty sand (SM):* We identified material as silty sand with varying fines. We recommend an effective friction angle of 33°, similar to values used in the SBFCA FRWL levee evaluations.

4.4 Analysis Methodology

BCI performed two-dimensional, finite element analysis using SLOPE/W, Version 7.23, with the proposed strength values presented in Table 2.

For landside steady-state slope stability analysis, we used:

- The Spencer limit-equilibrium method of analysis.
- Effective shear strengths as shown in Table 2.
- Pore pressures imported from the SEEP/W models.
- A tension crack search, which prevents the application of unrealistic tensile strengths in the levee embankment.
- Failure surfaces that intersect the levee crown and are greater than a few feet deep in the levee slope.

- ULDC DWSE Steady-State Landside Slope Stability Criteria: Factor of Safety greater than 1.4.
- ULDC HTOL WSE Steady-State Landside Slope Stability Criteria: Factor of Safety greater than 1.2.

For rapid drawdown waterside slope stability analysis, we used:

- The three-stage rapid drawdown method in SLOPE/W, which follows the method developed by Duncan, Wright, and Wong.
- Both the effective and total strengths shown in Table 4, in accordance with the three-stage method.
- Pre-drawdown WSE equal to the DWSE and a 26-foot drop level as recommended by URS.
- Considered short period pool levels per USACE Manual for Levee Design and Construction (April 2010).
- ULDC RDD Waterside Slope Stability Criteria for short period pool levels: Factor of Safety greater than 1.0.

4.5 Analysis Results

We present the summary of our Slope/W steady-state landside slope stability analysis results using DWSE seepage conditions in Table 3, the summary of our Slope/W steady-state landside slope stability analysis results using HTOL seepage conditions in Table 4 and the summary of our rapid drawdown slope stability analysis results in Table 5. A discussion of the results for each cross-section follows.

Table 3: DWSE Landside Steady-State Slope Stability Results

Location	**DWSE 200-yr.+1' (NAVD 88) (feet)**	**Landside Steady-State Factor of Safety**	*ULDC Factor of Safety Requirement*
Station 20+46.18	67.20	2.28	*≥ 1.4*
Station 39+46.18	66.09	2.24	*≥ 1.4*

Table 4: HTOL Landside Steady-State Slope Stability Results

Location	**HTOL 200-yr.+3' (NAVD 88) (feet)**	**Landside Steady-State Factor of Safety**	*ULDC Factor of Safety Requirement*
Station 20+46.18	69.20	2.26	*≥ 1.2*
Station 39+46.18	68.09	2.19	*≥ 1.2*

Table 5: Rapid Drawdown Waterside Slope Stability Results				
Location	**Rapid Drawdown WSE**		**Waterside Factor of Safety**	*ULDC Factor of Safety Requirement for Short Lasting High Stage Event* [a]
	DWSE 200-yr.+1' (NAVD 88) (feet)	**Water Surface Drop (feet)**		
Station 20+46.18	67.20	26	1.18	*≥ 1.0*
Station 39+46.18	66.09	26	1.14	*≥ 1.0*

[a]Table 7-2. Urban Levee Design Criteria Summary for Intermittently Loaded Levees, May 2012 ULDC

4.5.1 Station 20+46.18

Figure 7 presents the DWSE landside steady-state slope stability analysis at Station 20+46.18. For the DWSE of 67.20 feet, the calculated factor of safety of 2.28 meets the ULDC factor of safety criterion of ≥ 1.4.

Figure 8 presents the HTOL landside steady-state slope stability analysis at Station 20+46.18. For the HTOL WSE of 69.20 feet, the calculated factor of safety of 2.26 meets the ULDC factor of safety criterion of ≥ 1.2.

Figure 11 presents the DWSE waterside rapid drawdown slope stability analysis at Station 20+46.18. For the DWSE WSE of 67.20 feet and a 26-foot water surface drop, the calculated factor of safety of 1.18 meets the ULDC factor of safety criterion of ≥ 1.0.

4.5.2 Station 39+46.18

Figure 9 presents the DWSE landside steady-state slope stability analysis at Station 39+46.18. For the DWSE of 66.09 feet, the calculated factor of safety of 2.24 meets the ULDC factor of safety criterion of ≥ 1.4.

Figure 10 presents the HTOL landside steady-state slope stability analysis at Station 39+46.18. For the HTOL WSE of 68.09 feet, the calculated factor of safety of 2.19 meets the ULDC factor of safety criterion of ≥ 1.2.

Figure 12 presents the DWSE waterside rapid drawdown slope stability analysis at Station 39+46.18. For the DWSE WSE of 66.09 feet and a 26-foot drop, the calculated factor of safety of 1.14 meets the ULDC factor of safety criterion of ≥1.0.

4.6 Conclusions

Our analysis indicates the Star Bend Setback Levee substantially meets the ULDC Slope Stability Criteria for intermittently loaded levees.

5. REFERENCES

Blackburn Consulting (BCI), November 2007, Addendum No. 1 to Geotechnical Report for Star Bend Setback Levee, Levee District No. 1, Sutter County, California, Prepared for Wood Rodgers, Inc. and Levee District No. 1.

Blackburn Consulting (BCI), October 2006, Geotechnical Report for Star Bend Setback Levee, Levee District No. 1, Sutter County, California, Prepared for Wood Rodgers, Inc. and Levee District No. 1.

Blackburn Consulting (BCI), January 2012, Geotechnical Design Recommendations Report, Feather River West Levee Project, Segment 7, Prepared for Sutter-Butte Flood Control Agency and HDR Engineering, INC.

Blackburn Consulting (BCI), May 2016 (concurrent), Technical Memorandum, Underseepage Analysis for Intermittently Loaded Levees, ULOP Geotechnical Evaluation, Prepared for Prepared for Wood Rodgers, Inc. and Sutter-Butte Flood Control Agency, Levee District No. 1.

Department of Water Resources (DWR), May 2012, Urban Levee Design Criteria (ULDC).

Department of Water Resources (DWR), November 2013, Urban Level of Flood Protection Criteria (ULOP).

MHM Incorporated, December 2010, Construction Completion Report for the Lower Feather River Setback Levee at Star Bend, Vol. 1, 2A, 2B and 3, Prepared for Levee District No. 1 Sutter County

URS, April 2015, Guidance Document for Geotechnical Analyses, Urban Levee Geotechnical Evaluations Project, Contract 4600008101, (ULE Guidance Document), Prepared for Department of Water Resources, Division of Flood Management (DWR).

URS, November 2008, Phase 1 Geotechnical Data Report (P1GDR) of the Sutter Study Area, prepared for the Urban Levee Geotechnical Evaluations Program (ULE)

Wood Rodgers, April 2016, Levee Profile: Post Construction Conditions, Star Bend Setback Levee, Prepared for Blackburn Consulting ULOP Geotechnical Evaluation.

6. LIMITATIONS

BCI prepared this TM for WR and the SBFCA to support the 200-Year ULOP Geotechnical Evaluation. This TM should not be used by others or for other projects without BCI's written permission.

BCI performed services in accordance with generally accepted geotechnical engineering principles and practices currently used in this area. We do not warranty our services.

The results and conclusions in this TM document substantial compliance with geotechnical aspects of design. This TM should not be interpreted as "certification" of the levee.

The analyses, results and recommendations presented in this TM are draft.

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FIGURES

Figure 1 – Vicinity Map

Figure 2 – Site Plan

Figure 3 – Surficial Geology Map

Figure 4 – Levee Cross Section - Typical

Figure 5 – Subsurface Profile For Cross-Section At Station 20+46.18

Figure 6 – Subsurface Profile For Cross-Section At Station 39+46.18

Figure 7 – DWSE Landside Slope Stability Analysis At Station 20+46.18

Figure 8 – HTOL Landside Slope Stability Analysis At Station 20+46.18

Figure 9 – DWSE Landside Slope Stability Analysis At Station 39+46.18

Figure 10 – HTOL Landside Slope Stability Analysis At Station 39+46.18

Figure 11 – DWSE Rapid Drawdown Slope Stability Analysis
At Station 20+46.18

Figure 12 – DWSE Rapid Drawdown Slope Stability Analysis
At Station 39+46.18

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APPENDIX A

Relevant Boring Logs and Cone Penetrometer Logs

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APPENDIX B

Relevant Laboratory Test Results

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APPENDIX C

Plans and Geologic Profiles from Addendum No.1
to Geotechnical Report

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APPENDIX D

Comparison of Material Strength Properties