TECHNICAL MEMORANDUM
UNDERSEEPAGE ANALYSIS FOR INTERMITTENTLY LOADED LEVEES
ULOP GEOTECHNICAL EVALUATION
STAR BEND SETBACK LEVEE
Sutter County, California

Prepared by:

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May 2016

Prepared for:

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Geotechnical ▪ Geo-Environmental ▪ Construction Services ▪ Forensics

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**
Underseepage Analysis 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 underseepage 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 underseepage criteria outlined in the May 2012 Urban Levee Design Criteria (ULDC) Section 7.5.

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

2. SCOPE OF SERVICES

We performed the following to prepare this TM:

- Reviewed the Star Bend Setback Levee construction documents.
- Reviewed our 2006 BCI Star Bend Setback Levee and 2007 Addendum No. 1 to Geotechnical Report underseepage analysis.
- Reviewed our 2006 Geotechnical Report and 2007 Addendum No. 1 to Geotechnical Report subsurface explorations and laboratory test data.
- Prepared two representative subsurface cross-sections for underseepage 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 underseepage analyses 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 silt/clay “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.
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 levee 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 to its ability to provide an urban level of flood protection meeting the ULDC Underseepage Criteria for Intermittently Loaded Levees.

4.1 Cross-Section Development

We selected two reasonably critical locations for underseepage analysis based on:

- Site subsurface conditions,
- Site geology and geomorphology (See Appendix B).
- Existing seepage cutoff wall depths.
- Landside and waterside features that influence seepage such as borrow site depressions and distance to the river channel.

The analysis cross-section locations are shown on Figure 2.

WR provided surface profiles for the two analysis locations extending from the center of the Feather River channel to 2,000 feet landward of the existing levee centerline. We include these profiles in Appendix D.

We developed a subsurface characterization profile for each analysis cross-section based on:

- Subsurface data contained in the 2006 Geotechnical Report and 2007 Geotechnical Report Addendum for design of the Star Bend Setback Levee.
- Setback levee and SB slurry wall construction details contained in the Construction Completion Report for Levee District No. 1 of Sutter County Lower Feather River Setback Levee at Star Bend by MHM (December, 2010).
- Existing explorations provided in Phase 1 Geotechnical Data Report (P1GDR) of the Sutter Study Area for the Urban Levee Geotechnical Evaluations Program by URS (November, 2008).

Boring logs and CPT plots used to develop our cross-sections are included in Appendix A.

4.1.1 Station 20+46.18

We selected a cross-section at Station 20+46.18 due to the relatively thin blanket, shallow aquifer and 42-foot deep SB slurry cutoff wall. To develop the subsurface characterization profile, we used two BCI borings (B5-06 and B2-07), one BCI CPT sounding (CPT3-07), one boring from the P1GDR (WL0001_039B) and one CPT from the P1GDR (WL0001_040C).

We present the subsurface characterization profile used in our Station 20+46.18 analysis in Table 1.

Table 1: Station 20+46.18 Subsurface Characterization Profile

USCS Designation		Profile Description	Elevation (feet) (NAVD 88)
(1) SB Cutoff Wall		Traditional SB slurry cutoff wall; Approximately 42 feet deep by 38 inches wide.	47.4 to 5.3
(2) CL		Newly compacted clay levee fill; Approximately 23 feet tall with a 20-foot crest and 3:1 slopes; Average relative density of 102% of ASTM 698.	71.0 to 47.4
(4) CL/ML		*Blanket*: Soft/desiccated clay/silt	47.4 to 40.0
(6) SP		*Aquifer:* Poorly-graded sand (Less than 5% fines)	40.0 to 17.5
(5) CL/MH		*Cutoff Layer:* Sandy clay/elastic silt	17.5 to -20.0
(7) SP-SM		Poorly-graded sand with silt (5% - 12% fines)	-20.0 to -50.0
(3) CL		Deeper clay	-50.0 to -69.0

The cross-section for Sta. 20+46.18 with explorations and subsurface characterization is shown in Figure 5.

4.1.2 Station 39+46.18

We selected a cross-section at Sta. 39+46.18 due to the relatively thin blanket, relatively thick aquifer and deeper SB slurry cutoff wall. To develop the subsurface characterization, we used three BCI borings (B3-06, B6-06 and B4-07), one BCI CPT (CPT4-07), and one CPT from the P1GDR (WL0001_037C).

We present the subsurface characterization profile used in our Station 39+46.18 analysis in Table 2.

Table 2: Station 39+46.18 Subsurface Characterization Profile			
USCS Designation		**Profile Description**	**Elevation (feet) (NAVD 88)**
(1) SB Cutoff Wall		Traditional SB slurry cutoff wall; Approximately 65.0 feet deep by 38 inches wide.	47.4 to -17.6
(2) CL		Newly compacted clay levee fill; Approximately 23 feet tall with a 20-foot crest and 3:1 slopes; Average relative density of 102% of ASTM 698.	70.23 to 47.4
(4) CL/ML		*Blanket*: Soft/desiccated clay/silt	47.4 to 35.0
(8) SM		Silty sand with variable percent fines	35 to 22.5
(6) SP		*Aquifer:* Poorly-graded sand (Less than 5% fines)	22.5 to -12.5
(5) CL/MH		*Cutoff Layer:* Sandy clay/elastic silt	-12.5 to -28.5
(8) SM		Silty sand with variable percent fines	--28.5 to -41.0

The cross-section for Sta. 39+46.18 with explorations and subsurface characterization is shown in Figure 6.

4.2 Water Surface Elevations

We present the water surface elevations (WSEs) used in our analysis in Table 3.

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.

Table 3: Water Surface Elevations Used In This Underseepage Analysis				
Cross-Section	**HEC-RAS SBFCA/ FRWL Station**	**DWSE (NAVD 88)**	**HTOL (NAVD 88)**	
		200-yr. + 1' (feet)	*500-yr. WSE* (feet)	200-yr. + 3' (feet)
Station 20+46.18	RM 18.30	67.20	70.74	69.20
Station 39+46.18	RM 17.86	66.09	69.49	68.09

4.3 Hydraulic Conductivity Selection

We present the hydraulic conductivity values used in this evaluation in Table 4, followed by our rationale in selecting the values.

To determine hydraulic conductivity values appropriate for this analysis, we compared hydraulic conductivity values used in our 2006 Geotechnical Report for Star Bend Setback Levee underseepage evaluation with SBFCA FRWL evaluations, ULE Guidance Document and Star Bend Setback Levee Construction Completion Report. A tabulated comparison of these hydraulic conductivity values is included in Appendix C.

Table 4: Hydraulic Conductivity Values Used In This Underseepage Analysis

USCS Designation		Soil Description	Kh (ft/day)	Kh (cm/s)	Kv/Kh	Kv (cm/s)
(1) SB Cutoff Wall		Soil bentonite slurry	0.00024	8.7×10^{-8}	1	8.7×10^{-8}
(2) CL		Mechanically compacted levee fill	0.028	1.0×10^{-5}	0.25	2.5×10^{-6}
(3) CL		Deeper clay	0.0112	4.0×10^{-6}	0.25	1.0×10^{-6}
(4) CL/ML		Soft or desiccated clay/silt blanket, upper layers	0.028	1.0×10^{-5}	0.25	2.5×10^{-6}
(5) CL/MH		Sandy clay/elastic silt	0.028	1.0×10^{-5}	0.25	2.5×10^{-6}
(6) SP		Poorly-graded sand (Less than 5% fines)	112	4.0×10^{-2}	0.25	1.0×10^{-2}
(7) SP-SM		Poorly-graded sand with silt (5% - 12% fines)	56.7	2.0×10^{-2}	0.25	5.0×10^{-3}
(8) SM		Silty sand with variable percent fines	11.2	4.0×10^{-3}	0.25	1.0×10^{-3}

<u>Hydraulic Conductivity Selection Rationale</u>

- *SB Cutoff Wall:* We selected the highest hydraulic conductivity from QC/QA testing of SB slurry wall during construction of the Star Bend Setback Levee cutoff wall.
- *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 show a Liquid Limit ranging from 22 to 45 with an average of 31, a Plasticity Index ranging from 7 to 29 with an average of 14, and a fines content ranging from 22% to 94% with

an average of 73%. Based on this information, we selected a Kv value of $2.5x10^{-6}$ cm/sec, which is comparable to values used in the area for this type of compacted levee fill and is the same value used in our 2006 Geotechnical Report.

- *Deeper clay (CL):* Subsurface explorations deeper than 50 feet identified a stiff high plasticity soil. The ULE recommends a range of Kv values from $1.0x10^{-6}$ cm/sec to $1.0x10^{-8}$ cm/sec for lean clay. For this analysis, we used Kv = 1.0x10-6 cm/sec, which is the same value used in our 2006 Geotechnical Report.
- *Soft or desiccated clay/silt blanket (CL/ML):* Borings and test pits identify a 10-foot thick clay and silt blanket. From the 2006 Geotechnical Report, which used field measured permeability correlations for soils and rocks per Milligan 1975, Kv values range from $7.0x10^{-3}$ cm/sec to $1.0x10^{-6}$ cm/sec. Similarly, the ULE recommends a range of Kv values from $1.0x10^{-5}$ cm/sec to $1.0x10^{-7}$ cm/sec and varying Kv/Kh from 0.25 to 1.0 to simulate full depth desiccation cracks. The SBFCA FRWL evaluations used a Kv value of $2.5x10^{-6}$ cm/sec for desiccated blanket layers, which is within range of the recommend ULE values. We conducted our analysis using a Kv value of $2.5x10^{-6}$ cm/sec with a Kv/Kh value of 0.25, which is more conservative than the analysis from the 2006 Geotechnical Report.
- *Sandy clay/elastic silt (CL/MH):* From the 2006 Geotechnical Report, Kv values range from $7.0x10^{-3}$ cm/sec to $1.0x10^{-6}$ cm/sec for elastic silts and $1.0x10^{-6}$ cm/sec to $1.0x10^{-8}$ cm/sec for homogeneous clays. Materials within this layer typically have higher blow counts ($N_{1,60} \geq 20$) and were encountered anywhere from 20 to 60 feet below the ground surface. For our analysis, we selected a Kv value of $2.5x10^{-6}$ cm/sec, which is near the lower extreme for silt and upper range for homogeneous clay.
- *Poorly-graded sand (SP):* Relatively clean poorly-graded sand with apparent density varying from very loose to dense. The ULE recommends a range from $5.0x10^{-1}$ cm/sec to $1.0x10^{-3}$ cm/sec. We conducted our analysis using a Kv = $1.0x10^{-2}$.
- *Poorly-graded sand with silt (SP-SM):* Poorly-graded sand with few fines and apparent density varying from medium dense to dense and located below the key layer. The ULE recommends a range varying from 1.0x10-2 cm/sec to 1.0x10-5 cm/sec. We selected a value of 5.0x10-3 cm/sec to conduct our analysis.
- *Silty sand (SM):* Silty sand with varying fines. Material apparent density varies from loose to dense. The ULE recommends a range varying from 1.0x10-3 cm/sec to 1.0x10-6 cm/sec. We conducted our analysis using the conservative value of Kv = 1.0x10-3 cm/sec.

4.4 Analysis Methodology

We performed two-dimensional, finite element underseepage analysis using SEEP/W, Version 7.23, with the hydraulic conductivity values presented in Table 4. We considered steady-state seepage conditions and applied the following boundary conditions to the models:

- Fixed-head set to the Feather River water surface elevation along the boundary nodes of the waterside levee slope and channel bottom.
- No-flow condition along the bottom of the model, and along both the waterside and landside vertical edge of the model.
- Potential seepage surface for nodes on the landside levee slope, ditches, basins, and ground surface.

The underseepage exit gradients are calculated as the difference in total head though a blanket layer divided by the thickness of the blanket layer. We calculated underseepage conditions at the landside levee toe and at landside depressions up to 300 ft from the levee toe.

The ULDC specifies that for DWSE conditions, the maximum allowable exit gradient at the landside levee toe is 0.5. For depressions landside of the levee toe, the maximum allowable exit gradient should be determined by interpolating between the maximum allowable exit gradient at the landside levee toe of 0.5 and the maximum allowable exit gradient at 150 feet landside of the levee toe of 0.8.

The ULDC specifies that for HTOL conditions, the maximum allowable exit gradient at the landside levee toe is 0.6. For depressions landside of the levee toe, the maximum allowable exit gradient should be determined by increasing the maximum allowable gradient for the DWSE condition by 20%.

4.5 Analysis Results

We present a summary of our SEEP/W underseepage analysis results using the DWSE in Table 5, and a summary of the SEEP/W underseepage analysis using the HTOL elevation in Table 6. A discussion of the results for each cross-section follows.

Table 5: DWSE Underseepage Analysis Results

Cross-section	**DWSE 200-yr.+1' (NAVD 88) (feet)**	**Exit gradient, i**			
		At Landside Toe	*ULDC Criteria*	Landside Depression	*ULDC Criteria*
Station 20+46.18	67.20	< 0.05	*≤ 0.5*	< 0.05	*≤ 0.57* [a]
Station 39+46.18	66.09	< 0.05	*≤ 0.5*	0.11	*≤ 0.68* [b]

[a] Interpolated for the distance of 37 feet from the landside levee toe to landside depression
[b] Interpolated for the distance of 90 feet from the landside levee toe to landside depression

Table 6: HTOL Underseepage Analysis Results

Cross-section	HTOL 200-yr.+3' (NAVD 88) (feet)	Exit gradient, i			
		At Landside Toe	*ULDC Criteria*	Landside Depression	*ULDC Criteria*
Station 20+46.18	69.20	< 0.05	≤ 0.6	< 0.05	≤ 0.69 [c]
Station 39+46.18	68.09	< 0.05	≤ 0.6	0.13	≤ 0.82 [c]

[c] 20% Higher than DWSE ULDC Criteria.

4.5.1 Station 20+46.18

The calculated exit gradient of < 0.05 at the levee toe for the DWSE underseepage analysis meets the ULDC exit gradient criterion of ≤ 0.5. At the depression, 37 feet landside of the levee toe, the calculated exit gradient of < 0.05 meets the ULDC exit gradient criterion of ≤ 0.57. Figure 7 presents the results of the DWSE steady state seepage analysis at Station 20+46.18.

The calculated exit gradient of < 0.05 at the levee toe for the HTOL underseepage analysis meets the ULDC exit gradient criterion of ≤ 0.6. At the depression 37 feet landside of the levee toe, the calculated exit gradient of < 0.05 meets the ULDC exit gradient criterion of ≤ 0.69. Figure 8 presents the results of the HTOL steady state seepage analysis at Station 20+46.18.

4.5.2 Station 39+46.18

The calculated exit gradient of < 0.05 at the levee toe for the DWSE underseepage analysis meets the ULDC exit gradient criterion of ≤ 0.5. At the depression 90 feet landside of the levee toe, the calculated exit gradient of 0.11 meets the ULDC exit gradient criterion of ≤ 0.68. Figure 9 presents the results of the DWSE steady state seepage analysis at Station 39+46.18.

The calculated exit gradient of < 0.05 at the levee toe for the HTOL underseepage analysis meets the ULDC exit gradient criterion of ≤ 0.6. At the depression 90 feet landside of the levee toe, the calculated exit gradient of 0.13 meets the ULDC exit gradient criterion of ≤ 0.82. Figure 10 presents the results of the HTOL steady state seepage analysis at Station 39+46.18.

4.6 Conclusions

Based on our analysis presented above, the Star Bend Setback Levee substantially meets the ULDC underseepage 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.

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 Sutter Butte Flood Control Agency (SBFCA) to support their ULOP finding. This TM should not be used by others or for other projects without BCI's written permission.

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.

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

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FIGURES

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APPENDIX A

Relevant Boring Logs and Cone Penetrometer Logs

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APPENDIX B

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

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APPENDIX C

Comparison of Material Hydraulic Conductivity Properties

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APPENDIX D

Levee Profile Cross-Sections: Post Construction Conditions