TECHNICAL MEMORANDUM

SEISMIC VULNERABILITY FOR INTERMITTENTLY LOADED LEVEES
ULOP GEOTECHNICAL EVALUATION
STAR BEND SETBACK LEVEE

Sutter County, California

Prepared by:

BLACKBURN CONSULTING
2491 Boatman Avenue
West Sacramento, CA 95691

May 2016

Prepared for:

Wood Rogers, Inc.
3301 C Street, Bldg. 100-B
Sacramento, CA 95816

West Sacramento Office:
2491 Boatman Ave. ▪ West Sacramento, CA 95691
(916) 375-8706 ▪ Fax (916) 375-8709

Main Auburn Office: (530) 887-1494
Fresno Office: (559) 438-8411
Modesto Office: (209) 522-6273

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**
Seismic Vulnerability for Intermittently Loaded Levees
ULOP Geotechnical Evaluation
Star Bend Setback Levee
Sutter County, California

Dear Mr. Punia,

Blackburn Consulting (BCI) prepared this Seismic Vulnerability for Intermittently Loaded Levees Technical Memorandum (TM) in accordance with our Subconsultant Agreement for the Star Bend ULOP Geotechnical Evaluation, effective April 1, 2016. This TM summarizes our Star Bend Setback Levee seismic vulnerability analyses for intermittently loaded levees.

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

Sincerely,

BLACKBURN CONSULTING

Morgan Wright, P.E.
Project Engineer

Rob Pickard, P.G., C.E.G.
Project Geologist

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

TECHNICAL MEMORANDUM
SEISMIC VULNERABILITY FOR INTERMITTENTLY LOADED LEVEES
ULOP GEOTECHNICAL EVALUATION
STAR BEND SETBACK LEVEE
SUTTER COUNTY, CALIFORNIA

TABLE OF CONTENTS

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 documents that the Star Bend Setback Levee seismic vulnerability evaluation conforms to the May 2012 Urban Levee Design Criteria (ULDC), Section 7.7.

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 the BCI 2006 Star Bend Setback Levee seismic liquefaction and seismic settlement analysis.
- Reviewed the BCI 2006 Geotechnical Report and 2007 Addendum No. 1 to Geotechnical Report subsurface explorations and laboratory test data.
- Performed updated seismic vulnerability evaluation using the required 200-year-return period ground motions.
- Performed seismic vulnerability analysis in accordance with the 2012 Urban Levee Design Criteria (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 previously performed the Star Bend Setback Levee liquefaction and seismic settlement analysis for the 2006 Geotechnical Report in accordance with the simplified Standard Penetration Test Analysis consistent with the National Center for Earthquake Engineering Research (NCEER) 1996 Workshop liquefaction evaluation criteria. Current ULDC seismic vulnerability evaluation includes consideration of liquefaction, seismic settlement, post-seismic slope stability and deformation analysis to identify if seismic damage is expected from a 200-year-return-period seismic event. The ULDC requires a post-earthquake remediation plan as part of a flood safety plan when you anticipate detrimental seismic settlement or deformation that can affect the level of flood protection. This TM provides our Star Bend Setback Levee seismic vulnerability analysis using the 200-year-return-period seismic event.

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 is for the Star Bend Setback Levee area is included in Figure 3. The typical levee cross-section detail is included in Figure 4.

4. EVALUATION

This section contains our Star Bend Setback Levee evaluation to provide an urban level of flood protection meeting the ULDC Seismic Vulnerability Criteria for Intermittently Loaded Levees.

4.1 Site-Specific Ground Motion

Peak horizontal ground acceleration (PGA) and earthquake moment magnitude (Mw) are needed to perform liquefaction analysis and seismic vulnerability evaluation. URS (2015) prepared 200-year Return Period Mean PHA [or PGA] Hazard maps for the Marysville, Sacramento and Stockton Regions that show PGA contours for a Vs_{30} condition of 335 meters per second (m/s) (Figure 6-2 of the ULE Guidance Document). The document estimates 0.125g PGA for the Star Bend Setback Levee site.

We calculated a site specific Vs_{30} equal to 250m/s (approximately 820 feet per second) based on estimates from blow count data shown on the exploratory borings completed for the project by BCI and URS (2007). The 250 m/s velocity corresponds to a Site Class D (Stiff Soil site). We performed a site-specific probabilistic analysis because the calculated site Vs_{30} profile is different than that used to develop the URS PGA map. We used a location near the central portion of the Star Bend Setback Levee for the analysis. We used the USGS 2008 Interactive Deaggregations website (https://geohazards.usgs.gov/deaggint/2008/) to complete the analysis and develop the

PGA at the Star Bend site for an earthquake with a 200-year return period. The USGS program is based on source and attenuation models as presented in Petersen, M. and others, 2008, "*Documentation for the 2008 Update of the National Seismic Hazard Maps, USGS OFR 08–1128*," available on the web at http://pubs.usgs.gov/of/2008/1128/. Our analysis indicates a PGA of 0.13g for the site and we have included our USGS 2008 Disaggregation results in Figure 4.

The difference in PGA values (0.125g compared to 0.13g) is likely due to the base ground condition modeled (slightly higher Vs_{30}) in the URS model and conservatisms built into the USGS probabilistic analysis. The USGS database for probabilistic analysis does not include the Midland Fault, a recently considered seismic source. The Midland Fault is a concealed, north-south trending reverse or reverse-oblique fault located near Rio Vista. BCI compared the PGA values obtained in this TM with the URS (2015) study, which included the Midland Fault as a seismic source. Based on our comparison, the inclusion of this seismic source does not significantly increase the 200-year return period PGA for the project.

Based on the above, we recommend a 200-year return period PGA of 0.13g for the Star Bend seismic evaluation. We also recommend a moment magnitude (Mw) of 6.5 in accordance with Section 6.7.2 of URS's (2015) ULE Guidance Document.

The Regional Fault map presented in Figure 5 shows the locations of faults in the region. The locations of the faults are based on the U.S. Geological Survey and California Geological Survey, 2010, Quaternary fault and fold database for the United States (USGS web site: http//earthquakes.usgs.gov/hazards/qfaults/).

4.2 Water Surface Elevations

We present the water surface elevation (WSE) conditions considered for analysis in Table 1.

URS provided the Average Winter and Average Summer WSEs for the Feather River West Levee in their Water Surface Elevations Used for Geotechnical Analysis – Sutter Study Area Technical Memorandum (May 2010). We used the higher of the two seasonal averages to conduct our liquefaction potential analysis.

Table 1: Water Surface Conditions Used in This Seismic Vulnerability Analysis

Cross-Section	HEC-RAS SBFCA/ FRWL Station	Average Winter WSE (NAVD 88) (feet)	Average Summer WSE (NAVD 88) (feet)
Station 20+46.18	RM 18.30	29.70	28.58
Station 39+46.18	RM 17.86	29.48	28.28

4.3 Liquefaction Potential Evaluation

We performed our liquefaction potential evaluation for a 200-year-return period seismic event with consideration of the ULDC and ULE Guidance Document. We evaluated liquefaction potential at seven boring locations based on geologic conditions, site location and the availability of quality field and laboratory data.

4.3.1 Initial Soil Type Screening

The ULE Guidance Document Segment 6.7.1 presents screening criteria for materials not critical to seismic performance. We present these screening criteria in Table 2 below. We screened Star Bend Setback Levee field explorations with consideration of these criteria prior to our liquefaction analysis. We considered materials identified as not critical to the levee seismic performance to be non-liquefiable or less likely liquefiable during our liquefaction potential analysis.

Table 2: Guidelines for Screening Levee Soils Not Critical to Liquefaction Potential Evaluation

Site Conditions Not Critical to Liquefaction Potential Evaluation	Soils Not Susceptible to Liquefaction

• Unsaturated soils located above the analysis WSE.
• Soils located below the greater of the following depths:
  o 50 feet below the landside levee toe,
  o Two times the levee height below the landside levee toe, or
  o Bottom of the river channel.
	• All soils with $(N_1)_{60\text{-}CS} \geq 23$
	• All soils classified as CH or MH
	• All soils classified as CL or ML with the following properties:
	  o Plastic Index ≥ 10
	  o Liquid Limit ≥ 35
	  o Water Content ≤ 0.8 x (Liquid Limit)
	• Compacted Fine-Grained Soil
	• Clayey Sand (SC) with $\geq 20\%$ fines

4.3.2 Analysis Spreadsheet Development

We developed spreadsheets to identify the liquefaction potential of the subsurface soil using the following:

- 1996 NCEER and 1998 NCEER/NSF Workshop on evaluation of Liquefaction Resistance of Soils by Youd et al (October 2001).
- Standard Penetration Test-Based Probabilistic and Deterministic Assessment of Seismic Soil Liquefaction Potential by Cetin et al (December 2004).
- CPT and SPT Based Liquefaction Trigger Procedures by R.W. Boulanger and I.M. Idriss (April 2014).

The liquefaction analysis spreadsheet input includes:

- Consideration of the log of soil borings with field notes.
- Sample depths and blow counts.
- Laboratory test data.
- Assumed unit weights per table 6-2 of ULE Guidance Document.
- The higher of either the Average Winter WSE of Average Summer WSE.
- Ground water elevation at time of drilling.
- Earthquake magnitude (Mw) of 6.5.
- PGA of 0.13g.
- Distance to fault of 33.6 miles.

The liquefaction analysis spreadsheet calculates and reports a soil layer's factor of safety against liquefaction. We classify the soil's liquefaction potential based on the calculated factor of safety as presented in Table 3.

Table 3: Liquefaction Potential Criterion

Liquefaction Potential Classification	Factor of Safety against Liquefaction
Non-Liquefiable	≥ 1.2
Likely Liquefiable	≤ 1.0
Less Likely Liquefiable	1.0 – 1.2

4.3.3 Results

Our liquefaction potential evaluation results are presented in Table 4 followed by a discussion of the results. Our liquefaction potential analysis spreadsheets are presented in Appendix D.

Table 4: Liquefaction Potential Results						
Cross-Section	**Boring**	**Presence of Likely or Less Likely Liquefiable Soils (Yes/No)**	**Liquefaction Potential**	**Thickness of Zone (Feet)**	**USCS**	**Factor of Safety against Liquefaction**
Station 20+46.18	B5-06	Yes	Less Likely	3.0’	SP	1.14 (Cetin) 1.15 (NCEES) 1.32 (Boulanger)
	B1-07	No	---	---	---	---
	B2-07	No	---	---	---	---
	WL0001_039B	No	---	---	---	---
Station 39+46.18	B6-06	No	---	---	---	---
	B3-07	No	---	---	---	---
	B4-07	No	---	---	---	---

We identified a 3-foot thick potentially liquefiable layer in Boring B5-06. This layer classified as “Less Likely Liquefiable” to “Non-Liquefiable” with a factor of safety against liquefaction between 1.14 and 1.32. We evaluated this potentially liquefiable zone for continuity with surrounding borings and subsurface information and determined that this zone is likely isolated within a non-liquefiable layer. We therefore determined that this isolated, relatively thin layer with a borderline factor of safety does not pose a detrimental liquefaction threat.

Other than the borderline case discussed above, the remaining evaluated soil layers classify as non-liquefiable. Therefore, seismic deformation analysis is not needed for this stretch of levee.

4.4 Conclusions

Our seismic vulnerability evaluation indicates that the site soils are not susceptible to detrimental liquefaction and seismic deformation per the 2012 ULOP criteria. We therefore classify the Star Bend Setback Levee as having a low seismic vulnerability and a seismic site safety plan is not needed.

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.

Boulanger, R. W., and Idriss, I. M., April 2014, CPT and SPT Based Liquefaction Triggering Procedures, Center for Geotechnical Modeling.

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).

Cetin, K. Onder, Seed, R.B. et al, December 2004, Standard Penetration Test-Based Probabilistic and Deterministic Assessment of Seismic Soil Liquefaction Potential, Journal of Geotechnical and Geoenvironmental Engineering.

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)

URS, May 2010, Technical Memorandum: Water Surface Elevations Used for Geotechnical Analysis – Sutter Study Area, Prepared for California Department of Water Resources.

U.S. Geological Survey, 17 May 2013. *2008 Interactive Deaggregations*. Web. 29 Apr. 2016. <https://geohazards.usgs.gov/deaggint/2008/>.

U.S. Geological Survey, 6 Apr. 2016. *Quaternary Fault and Fold Database of the United States*. Web. 29 Apr. 2016. <http://earthquake.usgs.gov/hazards/qfaults/>.

Youd, T.L., et al, October 2001, Liquefaction Resistance of Soils: Summary Report from the 1996 NCEER and 1998 NCEER/NSF Workshop on Evaluation of Liquefaction Resistance of Soils, Journal of Geotechnical and Geoenvironmental Engineering, Vol. 127, No. 10, pp. 817-833.

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.

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.

TECHNICAL MEMORANDUM
SEISMIC VULNERABILITY
ULOP GEOTECHNICAL EVALUATION
STAR BEND SETBACK LEVEE

FIGURES

TECHNICAL MEMORANDUM
SEISMIC VULNERABILITY
ULOP GEOTECHNICAL EVALUATION
STAR BEND SETBACK LEVEE

APPENDIX A

Relevant Boring Logs

TECHNICAL MEMORANDUM
SEISMIC VULNERABILITY
ULOP GEOTECHNICAL EVALUATION
STAR BEND SETBACK LEVEE

APPENDIX B

Relevant Laboratory Test Results

TECHNICAL MEMORANDUM
SEISMIC VULNERABILITY
ULOP GEOTECHNICAL EVALUATION
STAR BEND SETBACK LEVEE

APPENDIX C

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

TECHNICAL MEMORANDUM
SEISMIC VULNERABILITY
ULOP GEOTECHNICAL EVALUATION
STAR BEND SETBACK LEVEE

APPENDIX D

Liquefaction Analysis Tables