Geotechnical Evaluation of a Small Levee System for FEMA Certification

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Purpose

Provide an overview and an understanding for Cities/Counties/Districts of what it takes from a Geotechnical Engineering perspective to prepare a levee system for certification.
Introduction

Client: Sacramento Area Flood Control Agency (SAFCA)

North Area Streams Study Area located just north of Sacramento, California

Included five levee segments:

- Dry Creek right and left bank levees (3.8 miles)
- Arcade Creek right and left bank levees (4.2 miles)
- Natomas East Main Drainage Canal (NEMDC) east bank levee (3.9 miles)
Background

- SAFCA tasked with certifying these levees by 2020
- Kleinfelder reviewed multiple levee systems to identify areas of concern
Background – Phase 1

- Phase 1:
  - Data collection and Geotechnical Data Report

- Phase 2:
  - Engineering Evaluation and Problem Identification Report

- Phase 3:
  - Final Design and/or Levee Certification
Introduction

- Levee: Dry Creek right and left bank levees
- Length: Left bank levee 2.2 miles, right bank levee 1.6 miles
- Waterways: Dry Creek and Robla Creek
Phase 1
Existing Information

- Explorations: NAS Total
  - 145 borings
  - 49 CPTs

- Explorations: Dry Creek Only
  - 47 borings
  - 18 CPTs
  - Depths were mostly shallow

- Not Sufficient (depth and spacing)
Existing Information

- Sampling and Laboratory Testing
  - Most borings had 5’ sample intervals
  - Lab testing included:
    - Index and strength testing
- Not Sufficient (quantity and depth)
Existing Information

- **Geologic Mapping**

- **Right levee**
  - Channels, Modesto and Riverbank Formations

- **Left levee**
  - Channels, Vernal Pools, Modesto and Riverbank Formations

(Fugro WLA)
Existing Information

- Topographic Maps:
  - LiDAR
  - Site specific ground surveys

(Fugro West)
Existing Information

HEM Survey:
Geophysical survey that evaluates changes resistivity in subsurface conditions. Typically shows differences between high resistivity (sands) and low resistivity (clays)

(Fugro Airborne Services)
Existing Information

- As-Built Drawings:
  - 1950’s USACE Construction
  - 1995 and 1997 Construction
  - Final Construction Reports
  - Communication with field Geotechnical Engineer
Existing Information

- Construction Inspection Reports
  - Geotechnical inspector was available for consultation
  - Final construction reports detailing key trench depths
- Sufficient and Invaluable
Existing Information

- Past Performance:
  - Historic water levels
  - Flood patrol notes
  - Newspaper articles
# Historical Water Levels

## Summary of Historical Water Levels Observed in NAS

<table>
<thead>
<tr>
<th>Study Area</th>
<th>Gage / Observation Location</th>
<th>Approximate Gage / Observation Station</th>
<th>Date of Reading</th>
<th>Gage / Observation Reading (NGVD29)</th>
<th>Gage / Observation Reading (NAVD88)</th>
<th>100-year WSE (NAVD88)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry Creek</td>
<td>Bike Trail Crossing at Robla Creek</td>
<td>6092+00 (DCSL)</td>
<td>12/31/05</td>
<td>38.0</td>
<td>40.2</td>
<td>43.2</td>
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<td></td>
<td></td>
<td></td>
<td>1/11/05</td>
<td>33.9</td>
<td>36.1</td>
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<td></td>
<td></td>
<td></td>
<td>10/26/04</td>
<td>34.8</td>
<td>37</td>
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<td></td>
<td></td>
<td></td>
<td>12/16/02</td>
<td>36.0</td>
<td>38.2</td>
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<td></td>
<td></td>
<td></td>
<td>2/19/86</td>
<td>39.6</td>
<td>41.8</td>
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<tr>
<td></td>
<td>D15 Pump Station (Upstream)</td>
<td>7000+00</td>
<td>3/6/06</td>
<td>27.6</td>
<td>29.8</td>
<td>41.4</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>12/31/05</td>
<td>28.9</td>
<td>31.1</td>
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<td></td>
<td>2/19/86</td>
<td>36.8</td>
<td>39</td>
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<tr>
<td></td>
<td>D15 Pump Station (Downstream)</td>
<td>7000+00</td>
<td>3/6/06</td>
<td>28.7</td>
<td>30.9</td>
<td>41.4</td>
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<td></td>
<td></td>
<td></td>
<td>12/31/05</td>
<td>34.3</td>
<td>36.5</td>
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<td>2/19/86</td>
<td>36.7</td>
<td>38.9</td>
<td></td>
</tr>
</tbody>
</table>
## Historical High Water Marks

### Summary of Historical High Water Marks Observed in NAS

<table>
<thead>
<tr>
<th>Study Area</th>
<th>Observation Location</th>
<th>Approximate Observation Station</th>
<th>Date of Reading</th>
<th>Surveyed Elevation (NGVD29)</th>
<th>Surveyed Elevation (NAVD88)</th>
<th>100-year WSE (NAVD88)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry Creek South Levee</td>
<td>20' east of tracks</td>
<td>6002+00</td>
<td>1/2/97</td>
<td>31.7</td>
<td>33.9</td>
<td>41.4</td>
</tr>
<tr>
<td>Dry Creek South Levee</td>
<td>Northeast of Rio Linda Blvd bridge</td>
<td>6080+00</td>
<td>1/3/97</td>
<td>33.8</td>
<td>36</td>
<td>42.9</td>
</tr>
<tr>
<td>Dry Creek South Levee</td>
<td>Bike Trail</td>
<td>6092+00</td>
<td>2/20/86</td>
<td>38.5</td>
<td>40.7</td>
<td>43.1</td>
</tr>
<tr>
<td>Dry Creek South Levee</td>
<td>Dry Creek Rd at Robla Creek</td>
<td>6118+00</td>
<td>1/2/97</td>
<td>38.2</td>
<td>40.4</td>
<td>43.6</td>
</tr>
<tr>
<td>Dry Creek North Levee</td>
<td>WPRR</td>
<td>7001+00</td>
<td>1/10/95</td>
<td>37.8</td>
<td>40</td>
<td>41.4</td>
</tr>
<tr>
<td>Dry Creek North Levee</td>
<td>Ascot Ave between West 2nd and 2nd Ave</td>
<td>7055+/-</td>
<td>2/20/86</td>
<td>36.8</td>
<td>39</td>
<td>41.4</td>
</tr>
</tbody>
</table>
New Information

- Levee Inspection
- Borings
  - 6 borings
- Lab
  - Moisture content, unit weight, Atterberg Limits, grain size analysis
Phase 2
Reach Selection

- Levee Segments divided into reaches based on:
  - Subsurface conditions
  - Past performance
  - Construction/Remediation history
  - Geomorphology changes
  - Topographic features
  - Construction features
# Reach Selection

<table>
<thead>
<tr>
<th>Reach ID</th>
<th>Station Limits</th>
<th>Cross Section Station Location</th>
<th>Reach Details</th>
<th>Rationale for Reach Selection</th>
<th>Rationale for Cross Section Selection</th>
<th>Explorations in Cross Section</th>
</tr>
</thead>
<tbody>
<tr>
<td>DCSSL-1</td>
<td>6000+00 to 6011+50</td>
<td>6003+00</td>
<td>Levee Height: 6 to 12 feet (Elevation 48 to 47 NAVD88 Levee Toe: Elevation 26 to 40)</td>
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<td></td>
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<td>Crown Width: 15 to 30 feet</td>
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<td></td>
<td>Landside Slope: 2:1:1V with some oversteepening to 1:4:1:1V</td>
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<td></td>
<td>Waterside Slope: 3:1:1V to 2:6:1:1V</td>
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<td></td>
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<td></td>
<td>Approx. 100yr. WSE: 43.1 to 40.2 feet NAVD88 (Channel Invert Elevation 21 to 22)</td>
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<td></td>
<td>Past Performance: No known past seepage or stability performance issues</td>
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<td>Improvement History: As a result of the 1988 flood, levees were raised generally 2 to 3 feet to increase available freeboard in 1990's and widened approximately 10 feet on the landside</td>
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<td></td>
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<td>Embankment Materials: Embankment consists of clay and clayey sands</td>
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<td>Foundation Materials: The foundation blanket layer is clay and clayey sand ranging from 3 to 7 feet thick. Sand layers up to 11 feet are below the blanket layer and the material continued to alternate between clays, silts, and sands to the full depths of the explorations. In general, a sand layer is consistently present below approximate elevation -8. Hardpan soils were encountered below depths of about 5 feet beneath the waterside levee toe or 10 feet below the landside toe.</td>
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<td>The downstream (western) boundary of this reach is located at the intersection with the NEMDC. The upstream (eastern) boundary of this reach is located where the blanket materials begin to transition from fine grained clay to include silty and clayey sand at the ground surface including hardpan. The primary surficial units of the reach are mapped as Gnu (Upper Modesto Formation) consisting of unconsolidated gravel, sand, silts, and clay with Rich (Channel deposits) crossing the levee near the intersection with NEMDC. Yp (Yermal pool) consisting of seasonally submerged or saturated depression usually indicative of an underlying hardpan cross the levee near Station 010G+00 (FWLA 2011).</td>
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<td></td>
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<td></td>
<td>Similar stratigraphy (embankment &amp; blanket) and levee geometry (wret, slopes)</td>
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<td></td>
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<td>Similar construction and improvement history</td>
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<tr>
<td>WRARFC_007B, KSNAST_0168, WRARFC_007C, WRARFC_043C, K94b_BDT</td>
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</tbody>
</table>
Reach Limits
Analysis Cross Section

- Critical analysis cross section:
  - 1 section per reach
  - Based on:
    - Topography
    - Stratigraphy
    - Past performance
  - Representative for entire reach – Base model
  - Sensitivity analysis performed if needed
# Material Property Selection

## Material Properties for Analysis Table

**North Area Streams - Reach DCCL-1 - Station 6003+00**

<table>
<thead>
<tr>
<th>Material Description (Layer Variation)</th>
<th>Best Layer Details (at CL of area crown)</th>
<th>Field Test Data</th>
<th>Laboratory Test Data</th>
<th>Strength Related Interpretation of Field and Laboratory Data</th>
<th>Permeability Related Interpretation of Field and Laboratory Data</th>
<th>Estimated Permeability for Hydraulic Conductivity Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CL (18)(1)</strong> Embankment</td>
<td>3.5 23 41.5 24.0 8.5 0.3 to 2.5</td>
<td>EPT Vane Shear</td>
<td>Strength Index</td>
<td>Permeability Index Tests</td>
<td>Compaction Tests</td>
<td>Strength Parameters Selected for Analysis</td>
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<tr>
<td><strong>CL (18)(2)</strong> Embankment</td>
<td>0 1.5 47.6 43.5 3.5</td>
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</tr>
<tr>
<td><strong>ML (18)(3)</strong> Embankment</td>
<td>3.5 39.0 30.5 8.5 17 29 4.0</td>
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</tr>
<tr>
<td><strong>DG (18)(4)</strong> Geosynthetic</td>
<td>23 98 39.2 27.4 2.1 12 19 2.0</td>
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</tr>
</tbody>
</table>

**KLEINFELDER**

Bright People. Right Solutions.
Analysis

- Engineering analysis performed to evaluate:
  - Levee Geometry
  - Through Seepage
  - Underseepage
  - Waterside and Landside Slope Stability
  - Settlement
  - Seismic Evaluation

- Using 100-year WSE (1-percent chance flood)
Analysis Methods

- USACE guidelines were used for evaluation of seepage, stability, and settlement (EM 1110-2-1913, ETL 1110-2-569, and SOP SPK EDG-03)
- USACE process for National Flood Insurance Program (NFIP) guidance for levee system evaluation (EC 1110-2-6067)
- Code of Federal Regulations (44 CFR 65.10)
- DWR Urban Levee Design Criteria (ULDC) used for seismic
Analysis Criteria

- Through seepage: water exiting the landslide levee slope (daylight of phreatic surface) and presence of erodible soils
- Underseepage: Exit gradient less than 0.5 at landside levee toe
- Stability: Minimum Factor of Safety of 1.1 for Case II – Sudden Drawdown and 1.4 for Case III - Steady-State Seepage Condition
- Settlement: N/A – Proposed project does not involve new construction or modification to levee prism.
Analysis Results – Through Seepage

- Layer 3, construction to raise levee and reconstruct waterside/landside slope

Watch for daylight of phreatic surface on landside levee slope
Analysis Results – Underseepage

- Gradients calculated at the landside levee toe and at the bottom of any lower topography (i.e. ditches)
- Keyways from construction tip into hardpan
Analysis Results – Landslide Stability

- Landslide slopes typically 2H:1V
Analysis Results – Waterside Stability

Waterside slopes typically 2.5H:1V to 4H:1V
Analysis Results – Seismic Deformation

- Qualitative evaluation to estimate liquefaction potential of subsurface soils
- Deformation analysis performed only if soils are liquefiable under design ground motions
- 7 borings have potential liquefiable soils in the upper 10 feet
- All were thin, discontinuous layers
- Therefore, no deformation analysis was performed
Conclusions

- Geometry – meets criteria
- Through Seepage – meets criteria
- Underseepage – met criteria in all but 1 location which was further explored in Phase 3 and determined to meet criteria
- Landside stability – meets criteria
- Waterside stability – meets criteria
- Seismic – additional evaluation should be performed during design based on results of qualitative evaluation
Conclusions

○ Phase 3 –
  ○ One outstanding area needed additional review for Dry Creek left bank levee.
  ○ Additional exploration and revision to analysis confirmed it met criteria

○ Ready for Certification
Levee Certification

- Dry Creek right and left bank levees meet USACE levee criteria
- Registered Professional Engineer
- Preparation of Engineers Opinion for inclusion in Levee Accreditation Package
  Appendices for:
  - Embankment and Foundation Stability
  - Settlement Potential
  - Other Civil Components also included
Thank you!