Structural Considerations for In-Place Closure of CCR Impoundments

Don Grahlherr, P.E. ¹ and Christopher Lewis, P.E. ²

¹Tetra Tech, Inc. 6426 Horneker Road, Pacific, MO, 63069
²Tetra Tech, Inc. 400 Penn Center Blvd, Suite 200, Pittsburgh, PA 15235-5613

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OVERVIEW

Many CCR Impoundments will be triggered to close over the next three years due to the Initial Structural Integrity Assessment (Hazard/Stability/Safety Factor Assessments), Groundwater Monitoring (Detection), and Location Restrictions requirements as outlined in the CCR Rule. The design of necessary improvements to stabilize the impoundment and dam(s) during closure, and satisfy post-closure requirements may drive significant costs at many units. In-Place closure designs must meet the CCR Rule Major Slope Stability requirements and, when seeking deregulation of the unit, possibly more stringent criteria. We will cover the major slope stability requirements in the CCR Rule and methodologies for their evaluation, and discuss how the results pertain to a successful in-place closure. Considerations of stability during closure construction will also be discussed, including pre-planning and impoundment preparation, benefits of a Ground Control Plan to guide safe execution of construction over impounded CCR, and associated best practices. Additionally, enhancements to address stability and deformation issues, and achieve successful in-place closure will be covered.

The CCR Rule §257.102 (d) closure performance standard when leaving CCR in place requires:

**Major Slope Stability**

1) **Stability During Closure:** Safety and Ground Control During Impoundment Capping
2) **Post-Closure Stability:** Cap, Slopes, and Remnant CCR (slope stability, and EQ-induced displacements & settlements)
Covering each of these requirements in more detail:

1) **Stability During Closure**

**Pre-Planning and Impoundment Preparations:**
- Delineate more stable regions and less stable regions of impounded CCR
- Lower pool level (“Unwatering”)
- Institute provisions to promote drainage of impounded CCR (“Dewatering”)
- Stage construction from areas that are more favorable for staging & supporting fill and equipment
- Assess practical rate of construction v. schedule... *Are you being realistic??*

The closure process can be managed under a GROUND CONTROL PLAN (GCP) that incorporates:
- Personnel Training and Safety Protocols
- Best Practices for Impoundment Capping
- Observational Methods with Instrumentation
- Possibly Interim Exploration w/ In-situ Testing (e.g., FVS Testing, CPTu) in Areas Requiring Thicker Fills
- Engineer’s Means of Conveying Recommended Precautions and Practices to Manage Construction Over Problem Ground
- Owner’s Mechanism for Setting Minimum Safety Protocol for All Bidding Contractors
- Contractor’s Safety Tool

The goal is to establish a safe rate of construction that limits disturbance of impounded CCR and consumption of excessive fill material in the capping process.

2) **Post-Closure Stability**

**CCR Rule Stipulated Min Factors of Safety (FoS):**
- Static / Steady-State Seepage [FoS ≥ 1.5]
- Liquefaction (Triggering, Post-EQ) [FoS ≥ 1.2]
- Seismic (Dynamic) [FoS ≥ 1.0]
- EQ-Induced Deformations & Settlement

**Static / Steady-State Seepage** (Basic Process)
- Characterize materials (spatial distribution & properties)
- Determine anticipated post-closure configuration
- Identify more critical cross sections
- Define steady-state seepage conditions, and assess bases to differentiate between current v. post-closure
• Address need for additional information wrt subsurface conditions, geotechnical data & prevailing seepage conditions
• Perform limit equilibrium analyses
• Evaluate modifications to CCR unit if FoS is deficient

Once Static Stability is satisfied:

Seismic Related Considerations:
• Liquefaction (Triggering, Post-EQ) [FoS ≥ 1.2]
• Seismic (Dynamic) [FoS ≥ 1.0]
• EQ-Induced Deformations & Settlement

Liquefaction:
1. Triggering Analysis
   • The CCR Rule does not stipulate a “FoS against Triggering” in a pore-pressure based triggering approach (e.g., Youd, et al), nor other criterion when applying other methodologies.
   • The engineer decides under what criteria or at what thresholds “triggering” occurs.

2. Post-EQ Stability (Post-Liquefaction Stability)
   • The CCR Rule does stipulate a “Post-EQ FoS” ≥ 1.2

--- This is a demonstration of stability following the EQ event ---

Seismic:
Per the CCR Rule: “Seismic FoS means the FoS determined using analysis under earthquake conditions for a seismic loading event, based on the U.S. Geological Survey (USGS) seismic hazard maps for seismic events with a specified return period for the location where the CCR surface impoundment is located.”
Seismic (Dynamic) [FoS ≥ 1.0]
--- This is a demonstration of stability during the EQ event ---

PRELIMINARY ASSESSMENT OF CLOSURE PLAN
1. Review Static / Steady-State analyses, and assess if more critical surfaces (i.e., surfaces with FoS nearing 1.5) pass through significant zones of sensitive material or other suspect materials potentially susceptible to strength loss.
2. Perform simplified screening of embankment, foundation, and impounded materials for susceptibility to strength loss.
3. Conservatively classify zones from the standpoint of susceptibility to strength loss, assign post-EQ shear strengths, and perform Post-EQ analyses.
4. If in a moderate to high seismicity region, and unable to meet a Post-EQ FoS >> 1.2, consider modifying the Closure Plan.
5. Consider modifications and stability enhancements that mitigate the significance of suspect zones on overall stability in the post-closure configuration. For example:
   a) Re-contour the facility to lower heights along critical sections.
   b) If more critical failure surfaces are confined to the embankment and the impounded CCR, and seepage is a contributor, consider an inverted filter and buttress if space permits.
   c) If suspect materials exist in the foundation and space downstream is limited, ground improvement might be necessary.
   d) If practical, dewater substantive zones of the impounded CCR.

6. Proceed to Seismic-Related Evaluations

**SIMPLIFIED STEPS FOR SEISMIC EVALUATIONS**

1. Classify the CCR Unit (post-closure configuration) with regard to hazard potential, and anticipated seismic performance:
   a) Low, Significant or High Hazard
   b) Not Susceptible or Potentially Susceptible to Seismic Instability

2. Characterize the physical behavior and spatial distribution of materials anticipated to influence stability.
   • Sand-like
   • Clay-like
   • Borderline or Transitional

3. Screen Zones for “Susceptibility to Strength Loss.”

<table>
<thead>
<tr>
<th>In-Situ Test</th>
<th>Sand-like</th>
<th>Clay-like</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPT</td>
<td>( N_{1,60} &lt; 15 )</td>
<td>( N_{60} &lt; 6 )</td>
</tr>
<tr>
<td>CPT</td>
<td>( q_{t1} &lt; 75 )</td>
<td>Certain Ranges</td>
</tr>
</tbody>
</table>

4. Analyze Post-EQ stability, initially employing simplified screening and Post-EQ analyses (target FoS ≥ 1.2) using conservative shear strengths.

**If Step 4 yields a Post-EQ FoS < 1.2, then move to Step 5.**

5. If in a higher seismicity region, consider modifying the Closure Plan, incorporating stability enhancements if necessary.

6. Perform Triggering Analysis to evaluate if EQ prescribed in CCR Rule will trigger strength loss in questionable zones.
7. Incorporate refinements from the triggering analyses, and re-analyze Post-EQ stability.

If Step 7 yields a Post-EQ FoS < 1.2, modify the Closure Plan by incorporating stability enhancements to satisfy the FoS criteria.

Once the Post-EQ stability requirements are satisfied:

8. Evaluate seismic-induced deformations and settlements for the post-closure configuration.
   - The CCR Rule does not stipulate specific performance criteria.
   - The Engineer determines the acceptance criteria.

9. Assess “Seismic (Dynamic)” FoS, that is, stability during the EQ prescribed in CCR Rule, if previous steps aren’t conclusive or don’t provide sufficient demonstration.

EQ-Induced Deformations & Settlement
Once post-earthquake stability is acceptable, consider seismic deformation analysis:

- Preliminary Screening
- Pseudo-Static Procedure
- Newmark Analysis (No Cyclic Mobility)
- Numerical Modeling with No Cyclic Mobility
- Numerical Modeling with Cyclic Mobility

Seismic Factor of Safety:
- Seismic (Dynamic) [FoS ≥ 1.0]
- In moderate and high seismic hazard regions, the seismic coefficient method is not accepted for higher hazard structures, and either response-spectrum or time-history methods are required.
- (Reference: USACE ER 1110-2-1806, among other guidance relied on by the EPA in the CCR Rule)

--- Necessitates a Nonlinear Dynamic Analysis ---
- This involves a sophisticated level of analysis to substantiate that a Closure Plan is satisfactory!!!

CONCLUSION: Preferably, you arrive at a Closure Plan that does not necessitate such sophisticated analyses.

3) Enhancements to Address Stability and Deformation Issues

- Design and Install Geosynthetics to:
  - stabilize construction corridors
  - improve ground control during capping
  - provide an enhanced drainage boundary
  - reduce breadth of buttresses
- Re-contour CCR Unit / Relocate some impounded CCR
- Construct Buttresses (with Filters, if necessary)
• Dewater impounded CCR
  o Conventional shallow drains or swales, and sumps
  o Wick drains, deep aggregate drains
  o Vacuum-enhanced wellpoint systems
  o Deeper trench drains, such as constructed with a One-Pass (Multi-Functional) Trencher

• Ground Improvement:
  o Soil Mixing (shallow and/or deep)
  o Shear Walls / Barettes
  o Compacted Aggregate or Cement-Aggregate Piers