State of Colorado

Department of Natural Resources
Division of Water Resources
Office of the State Engineer
Dam Safety

GUIDELINES FOR PREPARATON OF SUBSURFACE INVESTIGATION PLANS

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Section 1. **Summary**

1.1 To perform investigations into or within 200 feet of embankment dams and appurtenant facilities, the following need to be addressed prior to equipment or personnel mobilizing for the investigation:

1.1.1 Subsurface Investigation Plan approved by the SEO including:

a. Objective of the investigations and specific Potential Failure Modes being addressed in the investigation
b. Investigation Team including Lead Geotechnical/Geological engineer and field engineers/geologists
c. Figures and description of the existing conditions
d. Investigation and in-situ testing procedures
e. Contingency plans

1.2 Acceptable investigation methods are drilling advanced with hollow stem auger or sonic methods. Other methods require SEO acceptance.

1.3 Acceptable backfilling methods and materials are tremie-placed cement-bentonite grout or continuously compacted bentonite pellets.

The following sections provide additional information and guidance.

Section 2. **Purpose**

2.1 This document establishes requirements and provides guidance for geotechnical investigations in jurisdictional dam earth embankments and/or their earth and rock foundations. The primary purpose is to ensure adequate forethought and planning is provided as might be necessary to prevent damage to dam embankments and their foundations during investigation operations, sampling, in-situ testing, grouting, instrumentation installation, and borehole abandonment.

Section 3. **Background and Potential Issues**

3.1 Performing subsurface investigations into, in close proximity to, or through embankment dams and their foundations may pose significant risk to the structures. Water, compressed air, and various drilling fluids used as circulating media while drilling through earth embankments and foundations present increased risk of damage to embankments and foundations. Potential damage includes:

- Hydraulic fracturing.
- Pneumatic fracturing.
- Heave/borehole collapse in granular soils.
- Creating preferential seepage paths due to improper backfilling.
- Inadequate protection of embankment from drilling fluids during foundation rock coring.
- Erosion and widening of cracks.
- Clogging filters or drains.

3.2 Additional information is available in the United States Army Corps of engineers Engineering Regulation ER 1110-1-1807, Drilling in Earth Embankment Dams and Levees (USACE, 2014).

Section 4. **Subsurface Investigation Plan**

4.1 An SEO approved Subsurface Investigation Plan is required prior to any subsurface investigation or work within 200 feet of all dams and appurtenant facilities. This includes activities related to investigation, maintenance, remediation, and instrumentation. In general, investigations should be targeted to obtain information related to a specific failure mode identified from a Potential Failure Mode Analysis (PFMA). If the structure has not had a PFMA, an evaluation similar to the PFMA process must be performed and presented in the Subsurface Investigation Plan. This section describes the minimum information that must be developed and included in the Subsurface Investigation Plan.

4.2 Objective Summary

The objective of the Subsurface Investigation Plan must be clearly summarized including:

4.2.1 The purpose of the investigations and the issues that require additional data collection.

4.2.2 Potential failure modes summary and how the data collected from investigations will target refinement of the failure modes.

4.3 Exploration Team

List members of the exploration team used in developing the Subsurface Investigation Plan and that will be implementing the plan in the field. Include name, organization, title, registration, and years of relevant dam engineering experience for drill rig operators, field supervision personnel, lead geological/geotechnical engineer and field geologists/engineers. The drilling program must be prepared by experienced geotechnical/geological engineers familiar with subsurface exploration techniques and methods for dams. The Lead geological/geotechnical engineer must meet the minimum requirements of Rule 4.10 (2020 Rules).

4.4 Essential Geologic and Engineering Drawings

The Subsurface Investigation Plan must include drawings depicting the current understanding of subsurface conditions as they relate to the proposed work. These drawings typically include information of the foundation and embankment shown on a plan with previous and proposed subsurface investigation locations, profile drawings, and sections of the embankment in the areas proposed for exploration. The sections must be drawn to scale with no vertical exaggeration and must show the proposed borings along with available factual information and appropriate geologic or engineering interpretations. The information should include a summary of all data significant to the analytical and exploration needs such as:

4.4.1 Embankment description

a. Zones
b. Berms
c. Blankets
d. Filters

e. Drains
f. Geologic contacts
g. Known or potential defects

4.4.2 Piezometer locations showing screened influence zones and representative piezometric levels at the anticipated reservoir level during the investigation.

4.4.3 Plots of historic piezometric data related to reservoir level over time and reservoir level versus piezometer level.

4.4.4 Other instrumentation such as inclinometers, movement monuments, etc., shown in the context of the geologic contacts.

4.4.5 Location of all appurtenant structures.

4.5 Investigation Scope and Methodology

The Investigation program must include a summary of the scope and methods that will be used, including the following:

4.5.1 Number and location of proposed borings. Depth, diameter, bearing, and inclination of borings.

4.5.2 Number and location of proposed test pits or other investigations. Depth, orientation, width, and length in relation to the dam, methods to maintain excavation and dam stability and control groundwater.

4.5.3 Schedule when collected data will be reviewed during investigation by the lead geotechnical/geological engineer.

4.5.4 Sampling methods (disturbed or undisturbed), size, location, and proposed laboratory testing.

4.5.5 Proposed in-situ testing and methods for minimizing risk of hydraulic fracturing of the fill, foundation soils, and bedrock, as applicable.

4.6 Drilling methods.

Advancement of borings through the embankment and soil foundations with hollow stem augers or sonic methods are acceptable. Any other method of drilling through the embankment and soil foundations will need to be evaluated and accepted by the SEO prior to field work beginning. Core drilling with fluids in bedrock is acceptable. The risks must be described in the Subsurface Investigation Plan and specific procedures shall be employed to minimize the possibility for damaging the dam or foundation.

4.6.1.1 When core drilling rock, the embankment or foundation soil above top of rock must be protected and isolated from the circulating drilling fluid. Fractures in the bedrock must be considered as potential flow paths in contact with the overlying soil.

4.6.1.2 Considerations for artesian conditions need to be included in the Subsurface Investigation Plan and including materials onsite to plug the investigation if an emergency condition develops. Artesian conditions could significantly increase the risk of internal erosion at the investigation.

4.6.2 Types of instrumentation including the influence zone, filter compatibility of new materials with existing embankment material, materials to seal the instrument, etc.).

4.7 Backfilling borings.

4.7.1 All borings will be backfilled tremie placed cement-bentonite grout or continuously compacted, wax-coated, small-diameter bentonite pellets. Completing a borehole by backfilling with drill cuttings is not acceptable. Gravity grouting techniques should be used for backfilling boreholes. The plan shall evaluate the potential encountering low density zones and identify acceptable grouting rates, stages, and pressures to reduce the potential for hydraulic fracturing. Grout takes shall be measured.

4.7.1.1 Identify the grout mix proportions prior to the investigation and have excess materials onsite to address issues. The grout shall be at least the shear strength of adjacent materials, or as required by instrumentation manufacturers.

4.7.1.2 For filters and drainage portions of the dam, the borehole must be backfilled by tremie placement of granular materials that are designed to be filter compatible with adjacent materials, provide drainage and not segregate during placement.

4.7.1.3 Borehole completion documentation shall include intervals of backfill materials, calculated volume of material necessary to fill each interval, and actual volume of material required to fill each interval. Detailed records of borehole completion are vital and, as in the case of backfill material volumes significantly higher or lower than calculated, may be indicative of conditions significantly different than anticipated.

4.8 Test pit excavation and Backfilling

4.8.1 Excavation of test pits in dams needs to be considered carefully should be used if it is the only method to collect the required data identified in the PFMA. Test pits shall be approved by the SEO as part of a Subsurface Investigation Plan.

4.8.1.1 The stability of the planned excavation and the overall dam (as applicable) should be evaluated and documented as part of the Subsurface Investigation Plan.

4.8.1.2 The size of the excavation shall be the minimum required to obtain data and will be backfilled immediately after excavation. Engineering representative shall be on-site at all times during excavation and backfilling.

4.8.1.3 The excavation shall be backfilled and compacted with appropriate materials to restore internal zoning.

4.8.1.4 Groundwater shall be controlled at all times and the excavation shall be performed in the dry. Dewatering methods shall be included in the Subsurface Investigation Plan.

4.8.1.5 Designed filter material shall be stockpiled adjacent to the excavation prior to commencing work. The excavation shall be immediately backfilled with filter material if erosion or movement of materials is identified.

Section 5. **Contingency Plan**

5.1 Include an evaluation of potential issues that could arise and damage the dam. Include communication protocols, methods, and materials to address issues including:

5.1.1 Monitoring of the embankment and equipment operation during investigation. Contingency plan if there is a loss of drilling fluid or observations of the distress in the investigation or dam.

5.1.2 Monitoring adjacent instruments for deviations from historic performance. The dam Emergency Action Plan should be reviewed and available to Investigation Team members along with a clear line of communication from the field team to the dam owner and the SEO.

5.1.3 Availability of emergency response materials including equipment and supplies onsite (communications devices, filter materials, grout materials, packers, etc.).