DEPARTMENT OF THE ARMY ER 1110-1-1807
U.S. Army Corps of Engineers
CECW-CE Washington, DC 20314-1000

Regulation
No. 1110-1-1807 31 December 2014

Engineering and Design
DRILLING IN EARTH EMBANKMENT DAMS AND LEVEES

1. Purpose. This regulation establishes policy and requirements and provides guidance for drilling in dam and levee earth embankments and/or their earth and rock foundations. The primary purpose of this regulation is to prevent damage to embankments and their foundations from hydraulic fracturing, erosion, filter/drain contamination, heave, or other mechanisms during drilling operations, sampling, in-situ testing, grouting, instrumentation installation, borehole completion, and borehole abandonment.

2. Applicability. This regulation applies to all major subordinate commands (MSC), district commands, laboratories, and field operating activities having Civil Works and/or Military Program responsibilities. It applies to in-house and contracted drilling efforts for earth embankments or foundations associated with all dams and levees that have a federal interest.

3. Distribution. This regulation is approved for public release; distribution is unlimited.

4. References. References are listed in Appendix A.

5. Background. Drilling into, in close proximity to, or through embankment dams and levees and their foundations may pose significant risk to the structures. Water, compressed air, and various drilling fluids have been used as circulating media while drilling through earth embankments and their foundations. Although these methods have been successful in accomplishing the intended purposes, there have been incidents of damage to embankments and foundations. While using air (including air with foam), there have been reports of loss of circulation with pneumatic fracturing of the embankment as evidenced by connections to other borings and blowouts on embankment slopes. While using water and drilling mud as the circulating medium, there have been similar reports of erosion and/or hydraulic fracturing of the embankment or foundation materials. Conversely, there have been cases where heave, borehole collapse and significant disturbance have occurred while drilling in granular materials below the groundwater level. This typically has been the result of not using a proper drilling fluid to balance the water pressures in the soil or using high energy systems that induce heave in order to evacuate the cuttings. There is a delicate balance between too much induced fluid pressure that will cause hydraulic fracture and not enough fluid pressure that will result in borehole instability, heave, or significant sample disturbance. Other potential damaging effects include: creating preferential seepage paths due to improper backfilling, inadequate protection of embankment from drilling fluids during foundation rock coring, erosion and widening of cracks, and inadvertently clogging filters or drains with drilling fluid or grout. All drilling and associated activities that use fluid or other circulation or stabilization media need to be evaluated for the potential to hydraulically

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fracture the embankment or foundation. These activities include but are not limited to the use of drilling fluids, backfilling borings after completion, backfill grouting of instrumentation, backfill grouting of casings, water testing for permeability, piezometer rehabilitation, etc. The risk will vary with the selected methods and the site conditions. Every drilling operation must be well thought out and must have benefits of successful completion that confidently outweigh the risk of potential negative impacts. The following paragraphs describe the general concerns associated with each type of potential damage.

a. Hydraulic Fracturing. Excessive pressures from water, air, drilling fluid, or grout can fracture embankment and foundation materials. Hydraulic fracturing problems have occurred while drilling in embankments as evidenced by reports of loss of fluid circulation, blowouts into nearby borings, seepage of drilling fluids on the face of the embankment, and other similar situations. Hydraulic fracture can occur in both cohesive materials and cohesionless materials, and bedrock. It has been found that in soils, hydraulic fracturing can occur when the borehole pressure exceeds the lowest total confining stress (minimum principal stress σ_3) plus some additional strength. The additional strength can be approximated by the undrained strength of the soil. The minor principal confining stress (σ_3) in a normally consolidated soil with a level ground condition is typically the horizontal stress, which can be reasonably estimated. However, the minor principal confining stress in and under an embankment is difficult to determine and can vary significantly from idealized geostatic conditions. Effects from the side slope geometry, piezometric surface, abutment configuration, foundation rock geometry, embedded structures, compaction stress, and settlement history all are significant and can influence in-situ stress conditions. Typical drilling methods that use circulation fluids can quickly create induced fluid pressures that exceed the minimum confining stress. This often occurs when the return path for the fluid clogs and the induced pressures quickly increase. The use of non-pressurized stabilizing fluids is preferable, yet in some subsurface conditions, hydraulic fracture can occur under gravity pressure. Low stress zones may exist within and under embankments. It is possible for the confining stress in these locations to be much less than the gravity pressure exerted by a drilling fluid or grout. Certain embankment locations and conditions have a higher potential for hydraulic fracturing due to geometric configurations that create zones of low confining stress. Sherard 1973 and 1986 are good references that provide a comprehensive evaluation of the issues along with numerous case histories. Locations and conditions where hydraulic fracturing by drilling media is more likely to occur and have the higher potential of damaging the structure include the following:

(1) Near and over steep abutments that create low confining or tensile stress conditions.

(2) Adjacent to rock overhangs on abutments.

(3) Adjacent to buried structures or abrupt foundation geometry change that creates a differential settlement condition and a zone of lower soil stress transfer.

(4) Adjacent to conduits where narrow zones of soil backfill were placed between the structure and rock face.

(5) Dam cores that can experience more settlement than the adjacent shells.

(6) Dams in very narrow valleys. Arching keeps full confining stresses from developing.

(7) Near abutments where abrupt changes in geometry occur.

(8) In areas where the embankment is subject to differential settlement due to large differences in thickness of adjacent compressible foundation or embankment soils.

b. Erosion. The introduction of drilling fluids into cracks, either existing or formed by hydraulic fracture, can potentially cause erosion along the crack walls. This will enlarge the crack and could lead to an increased potential for internal erosion. Existing subsurface cracks are common in many dams and are often the result of differential settlement. The locations most at risk for existing cracks are typically the same areas that have low confining stress and have the highest risk for hydraulic fracture to occur.

c. Contamination of Filter/Drainage Features. In addition to hydraulic fracturing, the use of drilling fluids can pose a contamination risk for internal drainage features if the drill fluid or sealing grout migrates into and clogs the drain materials. Avoid drilling near drains or seepage blankets that may become contaminated by fluids. If drain penetration is justified, special provisions must be taken to prevent contamination. Special provisions may also be required for protecting the drainage features while backfilling the hole (such as placement of filter material through the zone of the drain or filter and installing lower and upper seals).

d. Heave and Sample Disturbance. Drilling programs that include performing in-situ tests or undisturbed sampling may require the use of drilling fluid to offset the confining stress relieved by the drilling of the hole. There have been cases where the failure to prevent stress relief or heave of granular soils below the water table have led to invalid in-situ test results and subsequently invalid interpretation of the subsurface conditions. This has occurred for both tests performed in drill holes and test performed in casings installed by methods that did not control heave or disturbance. Reclamation DSO 98-17 (1999) contains methods to deal with heaving sands while drilling and performing Standard Penetration Tests. If high quality undisturbed samples of fine grained soils are required for shear strength testing, then drilling mud may be required to prevent the soil from failing in undrained triaxial extension. See Ladd and DeGroot (2004) for a discussion on clay sample disturbance due to drilling.

6. Policy. This regulation provides guidance for investigation, maintenance, and remediation drilling in and near embankment dams and levees and/or their earth and rock foundations. including investigation planning, site preparation, borehole advancement, subsurface testing, instrumentation installation, piezometer and well rehabilitation, grouting, and borehole completion. It identifies drilling program plan requirements, restrictions on drilling fluids, drilling procedures to minimize risk of damage, borehole completion requirements, and prescribes personnel requirements, and the review and approval processes. It is the responsibility of the District Dam or Levee Safety Officer (DSO or LSO) to assure compliance with the restrictions and procedures outlined in this regulation.

a. Drilling Program Plan. An approved Drilling Program Plan (DPP) is required prior to any drilling, sampling, grouting, or any other invasive in-situ testing or exploration. This includes drilling activities related to investigation, maintenance, and remediation. When planning an investigation or remediation program, the data needs must be weighed against the potential risks of damage created by the drilling process. In general, all drilling and investigation should be targeted to obtain information related to a specific failure mode identified from a Potential Failure Mode Analysis (PFMA). For dams, the justification for drilling must include an approved recommendation from a risk assessment performed in support of the Dam Safety risk management process described in ER 1110-2-1156 Safety of Dams - Policy and Procedures. If the structure has not had a PFMA, a thorough evaluation similar to the PFMA process must be performed and presented in the DPP to show that the drilling is justified. It is paramount that all existing subsurface information is thoroughly evaluated and understood by the exploration team prior to developing a plan for additional drilling. In order to understand and communicate subsurface conditions and estimate drilling risks, the existing subsurface information must be assimilated into essential plan and section drawings showing the proposed drill holes, target sample areas and/or proposed instrumentation. For critical or complicated drilling programs the Geotechnical and Geology Community of Practice leads can be contacted to obtain recommendations for subject matter experts to assist in developing the DPP. Specific requirements for the DPP are included in Appendix B.

b. Restrictions on the Use of Drilling Fluids. All drilling programs in dams and levees should be designed to minimize the need for any drilling fluid such as air, gas, water, mud, polymers, slurries or any other drilling fluid that could pressurize the borehole soils. If the drilling objective can be performed using dry methods such as augers or sonic drilling they should be employed in lieu of methods that require fluids. If drilling fluids must be used due to the drilling objective or the subsurface conditions, the DPP must contain an analysis of the potential to cause damage and a plan that covers the measures that will be used to minimize the risk. The use of pressurized air or foam should only be considered when drilling in materials that will not transmit pressures to the soil core or other critical features or when the air pressure is reliably isolated from the borehole soils. Drilling in an open graded rockfill shell may be an example of when using air may be appropriate. All DPPs that propose the use of stabilizing or circulating fluids or other media will require additional review and approval as described in paragraph 6f.

c. Drilling Procedures. As there are many existing and potentially new methods for drilling and sampling that may be implemented on dams and levees, this regulation will not provide specific procedures. Most procedures are documented in applicable standards and reference documents. There are however, some general procedures that should be followed when using drilling fluids to limit the risk of damage.

(1) Tools should be sized and designed to minimize the likelihood of the return flow clogging. Methods that require the cuttings to flow through a small annulus between the tools or casing and the borehole wall should not be used.

(2) If possible, fluid discharges from the bit should be upward. A downward discharge increases the chance of clogging which could lead to a pressure spike. A lateral discharge into the sidewalls could lead to excessive disturbance or erosion.

(3) Lower and raise drill tools slowly to avoid pressure changes in the drill hole; this is especially important when using tools with restricted annulus space below the groundwater table as the pressure changes are more severe and can lead to suction and surging problems.

(4) Drilling feed rate must be slow enough to avoid crowding the bit and, thus, minimize the chance of inducing fracturing. The bit must be of a design such that pressure buildup is minimized.

(5) Drilling media properties, pressure, and return should be continuously monitored. A floating needle pressure valve is required to record maximum pressure spikes that can occur instantaneously and are often unnoticed.

(6) In some conditions, casing can be advanced ahead of the drilling bit to reduce the risk of hydraulic fracturing by confining the drilling fluids within the casing.

(7) 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.

(8) In situations where the presence of significant artesian pressure is suspected, which are common at the toe of dams, it may be necessary to use weighted drilling muds or raise the drill rig or install surface casing for pressure control along with the use of drilling mud. In some cases there may be a high risk of initiating internal erosion by drilling borings or excavating test pits in these areas. Emergency materials to stop progressive erosion in an excavation, a trench, or a borehole must be on site and readily available. For this situation, it is recommended to stockpile fine (C33 concrete sand) and coarse processed aggregates to filter and plug the excavation. Specific details such as height of the drill pad and amount of surface casing must be developed on a case-by-case basis dependent upon specific site conditions.

d. Borehole Completion. All boreholes and other penetrations (including direct push sampling, Cone Penetration Test soundings, Standard Penetration Testing, Becker Penetration Testing,) in and around embankment dams and levees must be sealed after completion. Completing a borehole by backfilling with drill cuttings is not acceptable. All boreholes and similar penetrations in the impervious portions of an embankment dam or levee and their foundations must be backfilled by tremie placed cement-bentonite grout or bentonite pellets/chips. The DPP must address the possibility of confined and separate ground water aquifers and demonstrate safe completion which avoids cross-contamination and leakage. The grout must be designed to obtain strength equal to or greater than the soil. Note that some instrumentation installations may require additional considerations for the grout strength. Gravity grouting techniques should be used for backfilling boreholes. For borings that penetrate zones with low confining stress it is possible to induce hydraulic fracturing from the gravity pressure. When grouting borings in these locations or if significant grout losses are observed, the grout backfilling should be done in stages allowing the grout to set between stages. For pervious portions of the dam or levee, the borehole must be backfilled by tremie placement of granular materials that are sized to provide drainage without being susceptible to migration through the pervious embankment or foundation materials or segregation during placement. Lutenegger, et.al. (1995) is a good source for borehole backfill guidelines. Special procedures and materials may be required for installation of instrumentation in boreholes.

e. Drilling Personnel. Drill rig operators must have a minimum of 5 years experience drilling with the equipment and procedures described in the drilling program. The drill rig operator must also be familiar with these guidelines. All drilling activities on USACE dams or levees must be conducted in the presence of a geotechnical engineer that is a licensed professional engineer or a licensed professional geologist who will be responsible for maintaining the integrity of the structure.

f. Approval Requirements. Drilling Program Plans must be reviewed and approved by the District Dam Safety Officer (Dams) or Levee Safety Officer (Levees). If any drilling fluid or other stabilizing or circulating media is proposed, a technical review performed by the Geotechnical and Materials Community of Practice (G&M CoP) Standing Committee on Drilling and Instrumentation is required. The plan will then require approval from the District DSO/LSO pending satisfactory resolution of the technical review comments. The Standing Committee on Drilling and Instrumentation will be chaired by the G&M CoP Lead, co-chaired and managed by the Risk Management Center, and staffed with G&M CoP experts.

g. Reporting. All incidents of damage or potential damage related to drilling and associated activities for dams must be reported following procedures outlined in Chapter 13 Reporting Evidence of Distress in Civil Works Structures of ER 1110-2-1156 Safety of Dams- Policy and Procedures. Damage in levees must be reported to the Levee Safety Officers and Levee Safety Program Managers in the District, MSC, and Headquarters.

h. Exemptions. Drilling required for immediate emergency measures where delays required to develop the DPP and obtain approvals would result in unacceptable risk of damage or failure, may be exempted from the requirements to prepare a DPP by the District DSO/LSO. Emergency drilling should be appropriately expedited but should follow the general guidelines presented in this regulation. No other exemptions or deviations from these requirements may be made.

7. Environmental Operating Principles. The user of this ER, as a member of a Project Delivery Team, is responsible for seeking opportunities to incorporate the Environmental Operating Principles (EOPs) wherever possible. A listing of the EOPs is available at: http://www.usace.army.mil/Missions/Environmental/EnvironmentalOperatingPrinciples.aspx.

FOR THE COMMANDER:

WILLIAM H. GRAHAM
COL, EN
Chief of Staff

2 Appendices
Appendix A - References and Resources
Appendix B - Drilling Program Plan

APPENDIX A

References and Resources

Drilling Procedures

EM 1110-1-1804 Geotechnical Investigations (including Appendix F EM 1110-1-1906 Soil Sampling).

EM 1110-2-1908 Instrumentation of Embankment Dams and Levees.

EM 1110-2-1914 Design, Construction and Maintenance of Relief Wells.

EM 1110-2-2300 General Design and Construction Considerations for Earth and Rock-Fill Dams.

EM 1110-2-3506 Grouting Technology.

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ASTM D1587-08 Standard Practice for Thin-Walled Tube Sampling of Soils for Geotechnical Purposes, 2012.

ASTM D2113-08, Standard Practice for Rock Core Drilling and Sampling of Rock for Site Investigation, 2008.

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ER 1110-2-1156 Safety of Dams- Policy and Procedures.

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APPENDIX B

Drilling Program Plan

An approved drilling program plan (DPP) is required for any exploration or remedial drilling (including grouting) work to occur in or near an embankment dam or levee or their foundations. When drilling is justified, an exploration team must be formed to determine and document the drilling program components required to adequately and safely address the project needs. The exploration team must thoroughly discuss the drilling program to ensure that the program minimizes risk and meets the project goals. The drilling program must be prepared by experienced geotechnical engineers and/or engineering geologists familiar with subsurface exploration techniques and methods, with advice from drilling specialists. The Lead engineer on the exploration team must be a registered professional engineer. This section describes the basic information that must be developed and included in the drilling program.

a. <u>Objective and Justification</u>. The objective of the drilling program must be clearly summarized including the purpose of the drilling and how the borings, samples, testing, instrumentation, etc. will be used. The need for the drilling must be thoroughly justified. Drilling should be minimized by first utilizing non-destructive methods including parametric analysis, the use of published correlations, and non-destructive geophysical testing. The justification must include documentation that shows the purpose is based obtaining information related to potential failure modes identified in an approved risk assessment in support of the dam or levee safety program. If an approved PFMA or risk assessment has not been performed, the exploration team must perform a thorough evaluation similar to the PFMA process and present a valid justification demonstrating that the drilling is required to obtain information related to a credible potential failure mode.

b. <u>Exploration Team</u>. List members of the exploration team used in developing the DPP. Include name, organization, title, registration, and years of experience.

c. <u>Existing Information Review</u>. In order to understand subsurface conditions, justify additional drilling, and estimate drilling risks, all relevant existing information must be assimilated and reviewed by the exploration team and then concisely summarized in the DPP. Information review typically includes, but is not limited to:

(1) Geologic mapping, boring logs, driller's notes, and reports portraying information from previous investigations and construction.

(2) Geotechnical files and reports including Site Characterization Reports.

(3) Foundation Completion Reports.

(4) Embankment Construction Reports.

(5) Periodic Inspection or Periodic Assessment Reports.

(6) As-built drawings.

(7) Archived records.

(8) Other construction reports.

(9) Construction photos for both original embankment construction and any subsequent construction.

(10) Instrumentation plans, data, and reports.

(11) Project records available in district and project offices.

d. Essential Geologic and Engineering Drawings. The DPP must include a set of drawings depicting the current understanding of subsurface conditions, as they relate to the proposed work. This detailed set of foundation and embankment drawings typically requires a plan showing all 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 all available factual information and appropriate geologic or engineering interpretations. The drawings should be updated regularly during the drilling operations to show conditions encountered and adjust geologic interpretations to help guide the program. The information on the plan, profile and sections must be detailed and include a summary of all data significant to the analytical and exploration needs such as:

(1) Embankment zones, including added berms, blankets, filters, and drains.

(2) Details of subsurface material classification.

(3) Geologic contacts and continuity interpretations supported by all nearby drilling and sampling details.

(4) Depth of the top of rock and all other zones of importance.

(5) Piezometer locations showing screened influence zones and recorded piezometric levels tied to the reservoir water level.

(6) Other instrumentation such as inclinometers, movement monuments, etc., shown in the context of the foundation geology contacts and interpretations.

(7) SPT blow counts or other test results defining engineering properties.

(8) Geophysical data, where useful (e.g. cross hole shear wave velocity profiles).

(9) Estimated extent of any zones of interest, including natural and made-made (grout holes).

(10) Seepage areas tied to geologic units, where possible.

(11) Location of all structures, including seepage control features, outlet works, etc.

(12) Location and types of any distress features (seepage, wet spots, sand boils, sinkholes, etc.).

Maintaining updated geologic sections and a plan during the drilling operations is important for making exploration changes and for responding to unusual or unexpected conditions or events. The process for accomplishing this must be outlined in the drilling program.

e. Drilling Scope and Methodology. The drilling program must include a summary of the scope and methods that will be used, including the following:

(1) Number and location of proposed borings.

(2) Utilities, surface and underground obstacles, and accessibility.

(3) Materials expected to be drilled, sampled, and tested.

(4) Depth, diameter, bearing, and inclination of borings.

(5) Required sample type (disturbed or undisturbed), size, location, and reason for sampling.

(6) Proposed laboratory testing.

(7) Drilling, sampling, and testing methods.

(8) Details of the proposed tools and drilling equipment.

(9) Instrumentation and borehole completion requirements (influence zone, seals, etc.). Drill rig operators: Name and years of experience.

(10) Field Supervision Personnel: Name, organization, title, registrations, years of experience.

(11) Personnel responsible for logging materials and assuring geologic drawings are updated regularly during the drilling program.

f. Risk Evaluation. Include an evaluation of the risk of hydraulic fracturing, erosion, contamination of drainage features, heave, or any other damage. This should include:

(1) A detailed description of any drilling fluid used including details on the circulation system, locations where fluid will contact soil, and circulation pressures that will be used.

(2) Monitoring needs during drilling, and a contingency plan if loss of drilling fluid or other complications are observed during drilling.

(3) Measures to minimize the risk of damage to the dam or foundation.

(4) Measures to prevent the possibility of cross-contamination and leakage from confined and separate ground water aquifers.

(5) Measures to prevent drill contact with structural features, such as conduits.

(6) Nearby instruments whose behavior will be monitored during the investigation and the expected response including threshold and limit values, and contingency plans for unexpected response.

(7) An emergency action plan including a list of emergency equipment and supplies to have onsite (phone/radio, filter materials, grout materials, etc.).

g. DSO/LSO Certification. Provide a certification page with the signature of the appropriate DSO/LSO. The certification must state: This Drilling Program Plan has been developed and reviewed by experienced professionals and is in compliance with all the requirements of ER 1110-1-1807. The proposed actions are justified and have been developed to minimize the likelihood of damage to the existing structure.