United States Department of Agriculture
Natural Resources Conservation Service

Part 631 Geology
National Engineering Handbook

Chapter 2 Engineering Geology

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Chapter 2 – Engineering Geology

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631.0200 General

A. Introduction

(1) Engineering geology is the application of geologic knowledge to engineering problems to ensure that geologic factors are recognized and accounted for in the siting, design, construction, and operation and maintenance of engineering works. It is an inter-disciplinary practice that incorporates principles of geology, geotechnical engineering, and civil engineering to characterize the composition and behavior of Earth's materials and processes.

(2) Natural Resources Conservation Service (NRCS) geologists conduct engineering geologic investigations for the planning, siting, design, and construction of engineering structures and implementation of engineering conservation practices across a broad spectrum of programs carried out by the agency.

(3) Geologic investigations commonly conducted in the agency focus on siting and designing engineering practices, ranging from high-hazard classification earth fill dams to farm ponds and animal waste storage or treatment structures. Additionally, geologists investigate and characterize geologic conditions that may lead to engineering failure or deficiencies in existing and planned conservation practices.

(4) NRCS classifies dams according to the potential hazard to life and property if the dams suddenly breach or fail. See National Engineering Manual (NEM) Part 520–Soil and Water Resource Development, Subpart C–Dams for more definitions and information.

(i) High hazard potential dams are dams where failure may cause loss of life or serious damage to homes, industrial or commercial buildings, important public utilities, main highways, or railroads.

(ii) Significant hazard potential dams are dams in predominantly rural or agricultural areas where failure may damage isolated homes, main highways, or minor railroads, or interrupt service of relatively important public utilities.

(iii) Low hazard potential dams are dams in rural or agricultural areas where failure may damage farm buildings, agricultural land, or township and county roads.

(5) NRCS geologists consult with design engineers and other specialists to determine project needs and identify what level and intensity of geologic investigation is appropriate for the project.

(6) Cultural resources, wetlands, and endangered species must be respected while conducting field activities.

(7) The NRCS uses a nine-step planning process whenever it begins a project. Using this process for geologic investigations helps personnel plan, site, design, and implement investigations under established NRCS standards and policies See https://www.nrcs.usda.gov/wps/portal/nrcs/detail/ny/technical/cp/?cid=nrcseprd1405629 (accessed 3-2022).

B. Purpose

(1) This chapter provides geologists, engineers, and designers with the fundamentals of planning and conducting engineering geologic investigations for the NRCS. This handbook provides technical guidance to the engineering geologist in support of their

professional responsibility to aid in the planning, design, construction, and maintenance of engineered structures.

(2) Successful investigations require a working knowledge of engineering design and construction methods to appropriately describe and classify materials for engineering needs.

631.0201 Minimum Requirements for Engineering Geologic Investigations

A. Criteria

This chapter establishes the minimum criteria for reconnaissance, preliminary, and detailed site investigations that are acceptable for design and construction. Additional investigations may be needed, depending on the complexity of the site and the specific design requirements for the structure (e.g., hazard classification).

B. Structure Classifications

To establish criteria for geologic investigations, structure sites are categorized into two groups, according to the fill height of the structure, construction materials, purpose of the structure, and hazard classification, as illustrated in figure 2-1.

Figure 2-1. NRCS Structure Classifications.

Group	Hazard Classification	Height (ft)	Type or Function
Group A	High-hazard (H) dams Significant-hazard (S) dams Low-hazard (L) dams	Any Any >35	Any
	All structures, embankments, and practices with an Engineering Job Class VI and above as defined in Title 210, National Engineering Manual (NEM), Part 501, “Authorizations” (210-NEM-501.8).	Any	Any
	Any	>20	Concrete or masonry arch or gravity dams Drop spillways Box-inlet drop spillways Chutes
		≥20	Principle purpose is forming storage reservoirs for recreation, municipal water supply, or irrigation where the product of the storage (in acre-feet) times the height (in feet) of the dam is equal to or greater than 3,000
Group B	Any	Any	Dams, embankments, and engineering conservation practices that do not classify as Group A, including Low-hazard (L) dams with a maximum fill height of 35 feet or less, and conservation practices* such as Pond (378), Waste Storage Facility (313), Dike (356), Diversion (362), and Grade Stabilization Structure (410)

*Refer to NRCS National Conservation Practice Standards for more information.

631.0202 Levels of Engineering Geologic Investigations

A. Reconnaissance Level Geologic Investigations

(1) The purpose of a reconnaissance level investigation is to produce a general site characterization and assessment of site suitability for the project. Reconnaissance level investigations are conducted at the onset of a project to identify, assemble, and summarize the existing regional and local geologic data and information relevant to the site and project.

(2) Existing data are analyzed to determine their validity and to identify deficiencies and gaps. The results of a reconnaissance level investigation determine if a preliminary geologic investigation is required and if other technical expertise is needed to assist the project. Findings are also used to assess what additional data are needed to satisfy programmatic and engineering planning.

(3) All available data, maps, and reports are reviewed to assess overburden and bedrock geology, geologic structure, regional faulting, geomorphology, general soil types, groundwater conditions, topography, drainage, and other observations or findings relevant to the proposed conservation practice or structure.

(i) In addition to compiling the available geologic information, typical or known engineering design requirements for the project are identified. The type and amount of information needed to inform planning and design decisions varies, depending on the project goals and geologic setting.

(ii) Data gathered during the reconnaissance are primarily descriptive and should include the following (at a minimum):

- General geology of the site: surface and subsurface earth materials
- Geologic conditions that may affect erosion and sedimentation
- Geologic conditions that may influence groundwater movement and recharge
- General character of topography and stream systems
- Depositional environment
- Mapped soils
- General engineering properties of soil and rock materials
- Presence and activity of faults
- General relationship between the geologic conditions at the site and known or typical design requirements for the proposed conservation practice or structure
- Known or projected mining activities and oil or gas extraction
- Examination of historic aerial photography to understand the site’s land use and any changes over time
- Defining structural or cultural features in the area of interest (may include water wells, oil and gas wells, mine shafts, adits, quarries, sinkholes, faults and landslides)

(iii) A site visit is not required for a reconnaissance level investigation but may be beneficial to:

- Verify the accuracy or adequacy of existing data
- Assess the feasibility and suitability of the site for the proposed project
- Evaluate logistical considerations for additional investigation or project implementation
- Identify site-specific hazards or potential issues
- Observe existing conditions
- Assess the existing and past site performance

(4) Methods used to gather, analyze, and summarize data depend on the structure type and project goals.

(i) Software such as ArcGIS or AutoCAD are useful to assess, organize, and analyze geospatial data, produce and display maps, and to combine acquired and project-specific data.

(ii) Information and data pertinent to the project may be available through published and unpublished papers, reports, maps, records, and federal, State, and local government agencies. The information must be reviewed for deficiencies, and issues must be identified before the data may be used for the project.

(iii) Study project areas by obtaining and reviewing maps at both large and small scales, so that various levels of detail can be examined. Certain features, such as large geologic structures, may be apparent on small-scale maps only. Conversely, the interpretation of active geomorphic processes typically requires accurate, large-scale maps with tight contour intervals.

- Topographic maps provide information on landforms, drainage patterns, slopes, locations of prominent springs, seepage areas, quarries, aggregate pits, mines, roads, urban development, and agricultural areas.
- Generally, interpretation of topographic maps should proceed from small-scale (large-area) maps to large-scale (small-area) maps, as the geologic investigation proceeds from regional to site-specific.

(iv) Interpretation of landforms and drainage patterns can provide useful information for engineering geology. Topography is typically controlled by the underlying geology and may provide inference to its structure, composition, and the large-scale processes acting on them. The types and duration of geomorphic processes control the degree to which these geologic features are evident on the topographic maps.

- Geologic features are not equally apparent on all topographic maps, and specialized training, skill and effort are required to confidently make accurate geologic interpretations. Analysis of aerial photographs, in combination with topographic maps, is a common and effective method to interpret the geology and geomorphology of a site.
- Types of useful information that may be obtained or inferred from aerial photographs and topographic maps are typically very general and include physiography, rock types, geologic structure, and recent geomorphic development.

(v) High-quality geologic maps provide detailed information about petrology and rock group and formation descriptions, rock formation contacts, geologic structure, faulting, and depositional history. Small-scale maps are suitable for development of regional geology because they encompass large areas and can be correlated with aerial imagery of similar scale to infer features and general processes acting on the site. Large-scale geologic maps are available for many areas and provide more detailed, even site-specific, information. Large-scale geologic maps provide details including local fault and joint distribution, detailed rock unit descriptions and distributions, and thickness of overburden.

(vi) Mineral resource maps are important sources of geologic information. The USGS and State geologic service maps provide information on oil and gas lease areas and metallic mineral resource areas. Mineral resource maps also include information on natural construction materials such as quarries for stone, aggregate, sand, and gravel deposits.

(vii) Aerial photography, light detection and ranging (LIDAR) imagery, color-infrared photography (CIR), and other forms of remote sensing can provide useful and detailed information. These methods are especially effective when correlated with topographic and geologic maps to reveal insights about geologic structure, lineaments, drainage patterns, rock and soil characteristics, erosional features, and geomorphic history. Geologic hazards such as faulting, mass wasting, land subsidence, and sink hole development can often be recognized from aerial photography and remote sensing. Free historical images can be obtained at USGS Earth Explorer, Google Earth, and The National Archives https://www.archives.gov/research/cartographic/aerial-photography (accessed May 2022). USGS Earth Explorer is an online tool that searches and downloads free satellite, aerial imagery, and historical images.

(viii) Most states regulate water well installation and maintain databases of water well installation logs. Wells may be municipal, industrial, domestic, agricultural, or may have been drilled for exploration, monitoring, or production of hydrocarbon resources. The quality of data recorded on well logs is highly variable and depends on the individual who generated the record. Data commonly found on well logs include well depth and location, lithologic stratigraphy, water bearing zones, well specifications, date of completion, and drilling company name. See National Engineering Handbook (NEH) Part 631, Chapter 31 for further discussion on groundwater investigations.

(ix) USDA-NRCS Web Soil Survey provides additional information on soils. Soil survey maps also provide another source of surface conditions at the time of surveys (https://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx) (accessed March 2022).

(x) Common sources of published and unpublished data include, but are not limited to:

- USDA Forest Service (FS), and NRCS
- U.S. Department of Energy: Nuclear Regulatory Commission (NRC)
- U.S. Department of Interior: Bureau of Indian Affairs (BIA), Bureau of Land Management (BLM), Bureau of Reclamation (USBR), Fish and Wildlife Service (USFWS), U.S. Geological Survey (USGS), National Park Service (NPS), and National Biological Service (NBS)
- U.S. Department of Transportation: Federal Highway Administration (FHWA) regional and state division offices
- U.S. Department of Homeland Security: Federal Emergency Management Agency (FEMA)
- U.S. Environmental Protection Agency (EPA) regional offices
- State Geological Surveys, Departments of Natural Resources, Water Resource Agencies, Departments of Environmental Management, Commissions on Environmental Quality, Water Resource Boards, and Departments of Environmental Quality
- Highway departments
- State and private universities
- Geotechnical engineering firms
- Environmental assessment and remediation firms
- Professional societies

(5) Documentation and reporting the findings from a reconnaissance level investigation should be compiled in a written report providing interpretations of subsurface conditions and conclusions regarding project feasibility. The report should clearly

identify general assumptions about material types and earth processes as they relate to the engineering needs of the project. Additional informational needs should be discussed and the need for further investigation determined. See 631.0206 Outline of Geologic Report for additional guidance on geologic documentation. The included outline may be refined to suit the reconnaissance level investigation report.

B. Preliminary Level Geologic Investigations

(1) Purpose

(i) Preliminary level investigations incorporate findings from the reconnaissance level investigation but further define local site conditions as they pertain to the project's engineering needs. Preliminary investigations typically involve field work that is exploratory in nature and minimally invasive.

(ii) Preliminary level geologic investigations characterize local site conditions through direct field observation and are useful for identifying complex geologic conditions or hazards that may affect engineering design.

(iii) Ultimately, findings from the preliminary level geologic investigations are used to determine if there is a need to execute a detailed level geologic investigation.

(2) Planning Preliminary Level Geologic Investigations.

(i) The geologist and the design engineer discuss geologic conditions that may influence the design, construction, cost, and function of the proposed structure or project.

(ii) Preliminary information on the location of the proposed structure is essential. The following site information is needed:

- Proposed and alternate location(s) for structure
- Purpose of structure or practice
- Dimensions and footprint of the structure or practice
- Estimates of height of structure and volume of compacted fill required
- Estimated maximum and normal pool elevations (if applicable)
- Hazard classification of structure (see figure 2-2)
- Approximate area in reservoir basin (if applicable)
- Approximate location of auxiliary spillway(s) (if applicable)
- Approximate location of outlet structure (if applicable)

(iii) The geologist should make use of the general design, experience, and performance of similar structures in the area when planning a preliminary level investigation. Interviews with engineers or other technicians familiar with the design and operation of similar projects, and visits to similar projects during or post construction, may provide helpful insights. Available reports on laboratory analyses of local materials should be reviewed to determine physical and engineering properties for possible application to the site.

(iv) Preliminary level geologic investigations serve to bridge the gap between reconnaissance and detailed level investigations. Findings from the reconnaissance level investigation, combined with the available project information, are used to select the most appropriate exploration methods for an initial subsurface investigation.

(v) Preliminary level investigations are exploratory in nature. Therefore, subsurface investigations completed at this level are broad in breadth and minimally invasive. Subsurface investigations serve to generally define the distribution and character of subsurface materials and identify areas of concern or interest that warrant further study during a detailed level geologic investigation.

(3) Methods

(i) Field studies may include a thorough inspection of outcrops, cut banks, and other surface exposures, an examination of erosional surfaces, mass wasting, seeps, springs, and other conditions on and adjacent to the project site.

(ii) Hand auger borings, test-pits, and geophysical surveys or other methods may be useful during preliminary level investigations to generally characterize shallow stratigraphy and engineering properties of the underlying material. See National Engineering Handbook (NEH) Part 631, Chapter 3 for further discussion on engineering classification of earth materials. See NEH Part 631, Chapter 31–Groundwater, section 631.3110 Geophysical Data Collection, subsection G–Geophysical Surveys and subsection I– Geotechnical Exploration Logs, and current ASTM International Standard D6429 (Standard Guide for Selecting Surface Geophysical Methods) for a general discussion on geophysical exploration.

(iii) Examples of some geologic conditions that may be assessed during a preliminary investigation include:

- Depth to and type of bedrock
- Regional rock mass characteristics such as strike and dip, jointing, folds, and faulting (ASTM D5878)
- Depositional and formational history of overburden
- Classification of overburden and geologic materials as defined by the Unified Soil Classification System (USCS) (ASTM D2488)
- Presence of “problem” soils, including soils that are collapsible, expansive, dispersive, erodible, corrosive, or soluble
- Presence of naturally unstable slopes
- General occurrence and movement of groundwater
- Presence of liquefiable soils or soils prone to cyclic softening under seismic loading
- Potential for seismic loading (as determined by the USGS Unified Hazard Tool)

(4) Documentation and Reporting

(i) Findings from a preliminary level investigation should be compiled in a written report providing interpretations or assumptions of subsurface conditions and conclusions. The report should clearly identify site-specific observations about material types and earth processes as they relate to the engineering needs of the project.

(ii) Additional informational needs should be discussed and the need for a detailed level geologic investigation determined. See 631.0206 Outline of Geologic Report for additional guidance on geologic documentation. The included outline may be refined to suit the preliminary level investigation report.

C. Detailed Level Geologic Investigations

(1) Purpose

(i) Detailed level geologic investigations are conducted to verify and supplement reconnaissance level and preliminary level investigations and provide the designer with site-specific and quantifiable information for use in design and construction.

(ii) Detailed level investigations must be of sufficient scope to determine site conditions that may influence the design, construction, and functioning of the structure. The extent of geologic investigation required for a site depends on the complexity of site conditions, size of the structure, potential damage if a failure occurs, and purpose and function of the structure.

(2) Planning a Detailed Level Geologic Investigation

(i) The goal of detailed level geologic investigations is to fully characterize and quantify site conditions for use in engineering design.

(ii) All members of the project team participate in planning to ensure that all critical needs are considered and addressed.

(3) Methods

(i) A detailed geologic investigation may include any combination of the following:

- Conducting invasive subsurface investigations, including exploration boreholes, soundings (e.g., CPTs), trenches, and test pits
- Geophysical surveys (see ASTM D6429)
- Seismic evaluations
- Obtaining soil and rock samples for laboratory analyses
- Performing in situ tests
- Reanalyzing remote sensing data and imagery with the engineering plans
- Evaluating the geomorphology, geologic units, and structures at or near the site
- Developing watershed sediment budgets and sediment storage requirements or sediment management, including sediment production, transport, and yield

(ii) A detailed site investigation provides information on subsurface conditions that cannot be obtained by surface examination or by shallow subsurface investigation. Equipment such as backhoes, bulldozers, power augers, or drill rigs are typically used to perform detailed site investigations with sampling and testing. The following information or assessments are commonly implemented:

- Test borings and soundings are used to investigate and log materials in critical areas such as the foundation, borrow source area(s), and spillway(s), to perform mass property testing of the earth materials, assess groundwater conditions, and to collect samples for further analyses.
- Test borings and soundings must be deep enough to characterize the earth materials to satisfy the needs or requirements of the engineering design of the project. The number and spacing of test holes must be adequate for correlation in both longitudinal and transverse directions and to the distance needed for complete interpretation of any condition that may influence structure or practice design.
- Trenches are especially useful for exposing and logging the geologic materials and shallow groundwater conditions in detail, as well as their structure over the length of the trench.
- Identify and locate geologic structural features, such as faults, folds, and joints. Obtain sufficient information about unconsolidated deposits to determine their location, thickness, and extent.
- Where drilling methods are used, the following tests are commonly used to characterize the in situ strength of foundation materials: standard penetration test (SPT), vane shear tests (VST), and cone penetrometer tests (CPT) (see ASTM D3441). Use professional judgement and experience when selecting the appropriate strength testing method for each site. Often, the required testing method is dependent on physical limitations dictated by local conditions, as well as the engineering design needs.
- Material behavior characteristics, engineering significance, and site conditions are evaluated to identify potential engineering problems and to

determine possible solutions. From this assessment, the geologist and designer determine sampling and testing needs, including what laboratory analyses are required for design and construction. This approach is useful for determining the type, number, and size of samples that must be gathered. Consultants, such as drilling contractors or technical laboratory specialists, may be useful when determining the most appropriate and feasible drilling, in situ testing, and laboratory testing methods. Consultants may also help establish practical time and budgetary estimates for these services.

- Samples are obtained using appropriate sampling procedures that follow industry standard best practices. Additional test holes or in situ field tests that are needed should be made during the detailed investigation.

(4) Documentation and Reporting

(i) Compile findings from detailed level investigations in a written report providing interpretations or assumptions of subsurface conditions, conclusions, and recommendations. The report must be comprehensive and address all concerns that pertain to the engineering design. Clearly identify and quantify site-specific observations about material types and earth processes as they relate to the engineering needs of the project.

(ii) At a minimum, detailed level geologic reports should document:

- Discussion of the foundation materials and conditions to serve as a basis for geologic interpretation and structural design.
- An assessment of fill materials and determination of suitability, quality, and quantity.
- Storage reservoir basins are free from sinkholes and caverns, permeable strata, fractures or fissures, and any other conditions that might lead to moderate or rapid water loss.
- Subsurface water conditions to the extent that they may affect the design of the structure or the construction operations.
- Stability characteristics for material in the auxiliary or other open spillways and channels under anticipated flow conditions during operation of the structure.
- Allocated sediment storage will not be exceeded during the design life of the structure.
- Seismic hazard risk and loading potential.
- Support the general nature of the design. For example, structures designed for waste or chemical storage should sufficiently protect groundwater and surface water from contamination. Any physical structure will be supported by the subsurface, and structures designed to hold water will indeed hold water to applicable standards.

(iii) The detailed level geologic investigation secures the above information and supplements the knowledge of the site gained through the reconnaissance and preliminary investigations to provide a comprehensive, qualitative, and quantitative characterization of the site as it pertains to engineering needs.

631.0203 Geologic Investigations for Group A Structure Sites

A. Purpose

(1) Group A structures (figure 2-1) are any high-hazard potential dams, significant-hazard-potential dams, and low-hazard potential dams over 35 feet in effective height and any project with a Job Approval Authority of VI or above, as determined by the

NRCS State Conservation Engineer (SCE). Geologic investigations and analyses are essential for conservation planning and the implementation of sound engineering practices for the protection of public health and property, safety, welfare, and the environment.

(2) The purpose of this section is to ensure that geologic, hydrogeologic, and geomorphic processes, conditions, and hazards, and the engineering physical properties of earth materials are properly and sufficiently characterized in support of NRCS conservation efforts.

B. Planning Group A Geologic Investigations

(1) The geologist and design engineer jointly develop a geologic investigation plan that describes what data to collect and how the data will be used to support sound engineering design.

(i) Preliminary findings are reviewed to determine the adequacy of the subsurface investigation plan, including in situ testing, the need for instrumentation, and sampling for laboratory testing.

(ii) The data are reviewed for adequacy for use in all stages of design and construction.

(2) Products and outcomes for geologic investigations of Group A dams may include, but are not limited to:

(i) Delineation and determination of engineering properties, continuity, relative permeability, and other characteristics of all materials to the specified depth beneath the entire base and abutment area, or area of influence, of the dam and outlet structures. The structural area of influence may be far into the abutments or may be the entire reservoir basin, under some geologic conditions or structure purposes. Stratigraphic and structural discontinuities, such as faults, joints, voids, and fractures with engineering significance must also be characterized.

(ii) Determination of the attitude, location, extent, and character of folds, faults, joints, lineaments, solution cavities, disconformities, and unconformities. Note the schistosity, slaty cleavage, and bedding characteristics. In some cases, angled borings may be needed to define hazardous conditions.

(iii) Delineating the incompressible rock surface, where it occurs within the depth of influence of the structure.

(iv) Evaluating the need for hydraulic pressure testing in rock foundations and abutments of proposed dams for water storage reservoirs.

(v) Assessing the influence of rock mass properties on the slope stability of rock materials in spillway cut slopes.

(vi) Determining the extent and character of materials to be excavated for open spillways and the character and slope stability of the material in the spillway cut slopes.

(vii) Locating and determining the depth, thickness, continuity, distribution, and engineering properties of the earth materials proposed for use as fill.

(viii) Determining the depth to groundwater, seasonal variation of water table, and extent and character of aquifers within the zone of influence of the structure.

(ix) Evaluating the need for controlling groundwater during construction and determining the need for controlling moisture content in borrow material.

(x) Evaluating the seepage potential of the permanent pool area and dam site of water-holding reservoir sites.

(xi) Evaluating whether economic mineral deposits, including sand and gravel, occur within the area of influence or would be preempted or otherwise impacted by the project. Also assessing the potential impact of current or future mining or oil or gas withdrawal from below or near the structure site.

(xii) Assessing the effects of earthquake loading on the proposed structure.

(xiii) Determining reservoir sediment storage requirements based on results of a watershed sediment yield study (see ASTM D4581).

(xiv) Evaluating slope stability of the reservoir and surrounding terrain.

(3) Non-dam projects may also be considered Group A when the Job Approval Authority is VI or above. This may include large tanks, waste treatment lagoons, or animal waste holding ponds for large Confined Animal Feeding Operations (CAFO). Products and outcomes for non-dam projects in this category include but are not limited to:

(i) Evaluating the subsurface for bearing strength as required for the type and size of the planned structure.

(ii) Evaluating the material at the site for use as a proposed earthen liner for animal waste (see NEH 651, Chapter 7).

(iii) Evaluating the site for construction and design considerations with regards to groundwater and any seasonal high-water table. This can be especially critical for synthetic-lined ponds or lagoons and for tanks that may become empty and buoyant.

(iv) Evaluating the sensitivity of the environment and susceptibility of water supply sources to contamination. Engineering controls should be implemented when needed to protect water supply from contamination.

(v) Evaluating the presence and type of rock and potential need for blasting.

(4) Use an engineering geologic map to identify and spatially represent zones of geologic material that meet similar engineering performance criteria. The map should provide the locations of all measurements, samples, or observations, and the data collected.

(5) Supplements may include structural contour maps showing elevations of geologic contacts, tops of key beds or other surfaces of interest, and isopach maps showing contoured thicknesses of each mapped unit. Cross sections, profiles, fence diagrams, columnar sections, perspective drawings, and other illustrations may be used to represent geologic features. In some cases, a geomorphic map, showing landforms, slope stability, and topography is appropriate.

C. Test Hole Locations and Depths

(1) All soil, geologic materials, and rock units need to be characterized beneath the footprint of the structure and the abutments.

(i) For all earth fill dams in Group A, borings at all stations within the footprint of the structure must be extended to depths equal to or greater than the equivalent proposed height of fill associated with the points of boring, or to hard, massive, unaltered rock or similar limiting layer.

(ii) For all concrete dams, borings must extend to depths equivalent to at least 1.5 times the proposed effective height of the dam as measured from the maximum proposed depth of excavation.

(iii) Record the depth to groundwater for each borehole.

(2) Sufficient borings must be made along the proposed centerline of dams to provide correlation of geologic materials and to define the rock surface profile. Borings must extend deep enough into rock to establish depth to unaltered bedrock.

(3) Sufficient borings must be made along the proposed centerlines of risers, inlet structures, or other conduits to provide correlation of geologic materials from the riser to the outlet, and to a depth equal to the zone of influence of the structure. At

least one test hole must be placed at the riser, at the intersection of the centerlines of the dam and conduit, and at the outlet.

(4) Sufficient borings must be made along the centerline of drop inlets or other conduits to provide reliable correlation of all strata from the riser to the outlet and to a depth equal to the zone of influence of the structure. Where rock occurs within the zone of influence, the investigation must accurately delineate the rock surface below the centerline of the conduit. Normally, bore holes are placed at the riser, at the intersection of the centerlines of the dam and conduit, and at the outlet, with sufficient holes in between to allow reliable correlation.

(5) The depth of investigation under the footprint of the structure must be equivalent to the proposed height of the structure unless hard, massive, or otherwise unaltered impervious rock is encountered at a shallower depth. Borings must extend far enough into rock to determine its character and condition and whether it is in situ.

(6) The minimum depth of borings in weak or compressible materials, where the influence of loading by the structure may be significant to depths greater than the height of the dam, will be determined in consultation with the design engineer. Depths of investigation ultimately depend on the significance of the material and mass characteristics of earth materials to the overall design.

(7) Hydraulic pressure tests must be made in rock foundations and abutments of proposed dams forming storage reservoirs. This test consists of a holding test of not more than one psi per foot of depth below ground surface, followed by a pumping test if the pressure drop in the holding test exceeds 10 psi.

(8) All borings must be sufficiently deep and closely spaced to establish reliable correlation of strata under the entire base of the structure. The number, depth, and the spacing of holes needed depend on the regularity, continuity, and attitude of strata and character of geologic structures.

(9) Where an excavated auxiliary spillway is planned, investigations must be of sufficient intensity to determine quantity and character of the materials to be excavated, limits of common and rock excavation, suitability of the excavated material for use in construction, and erodibility of the resulting spillway channel. Each boring for investigations must extend to a depth of not less than two feet below the bottom of the proposed auxiliary spillway. A sufficient number of auxiliary spillway holes must extend to the valley floor to determine the potential erodibility of the bulk of the material in the spillway. Each layer of earth materials must be characterized below the extent of the auxiliary spillway layout down to the valley floor.

(10) Enough borings must be made in the borrow areas to identify and establish the distribution and thickness of all materials to be used for fill. All borrow area borings should extend at least five feet below the expected depth to which material is to be removed, unless consolidated material that is not suitable for fill is found. Determine the depth to groundwater at the time of boring for all borrow area borings.

D. Structures with Permanent Storage

(1) For structures with permanent storage, undisturbed samples of all compressible, fine-grained materials are obtained for consolidation tests. Undisturbed samples are obtained from the foundation to a depth equivalent to the overall height of the dam, as measured from the lowest elevation on the downstream toe to the top of the dam (see ASTM D1587). If compressible materials or materials that may undergo liquefaction are suspected to occur at greater depths, extend testing to depths within the zone of influence.

(2) Samples for compaction and shear tests must be obtained from the borrow areas and auxiliary spillway areas. Conduct field crumb testing on borrow areas for dispersive clays on embankment fill materials (see ASTM D6572). Additional soil sampling and laboratory testing are required with positive field crumb test results or if dispersive soil is suspected. Investigations should also determine if dissolvable minerals exist in the dam foundation and abutments (e.g., salt and gypsum).

(3) For all dam sites with permanent storage, the groundwater regime and hydraulic characteristics of the entire reservoir area, the abutments, and embankment foundation must be evaluated to determine leakage potential and the need for reservoir sealing. Where significant leakage is suspected, samples must be obtained of materials underlying the permanent pool area to determine reservoir sealing requirements. Potential effects, including damages, of seepage from a reservoir on lands adjacent to or downstream from the structure must be evaluated.

E. Structures Subject to Subsidence

(1) A geologist must determine whether sinkholes, solution cavities, underground mine collapse, or the removal of fluids such as petroleum, water, and natural gas could impact the design, function, and safety of the structures, particularly by abrupt differential settlement.

(2) The geologist must provide recommendations to the design engineer on identified geologic concerns that need to be addressed in the operations and management plan for the structure. If studies indicate that the predicted subsidence cannot be remedied, the site must be abandoned. Subordination of mineral rights within a limited area at the site does not necessarily prevent subsidence of the structure.

F. Structures Underlain by Economic Mineral Deposits or Oil and Gas Deposits

(1) The geologist must identify and generally characterize any economic mineral deposits underlying the dam site that might be mined or extracted in the future.

(2) The geological investigation must encompass an area that extends outward beyond the base of the dam, a horizontal distance equivalent to the depth of the deepest mineral deposit below ground surface. This requirement may be modified because of a detailed site-specific study by, and at the consequent recommendation of, a qualified mining engineer.

(3) Additionally, oil or gas leases that may involve multiple wells or horizontal wells and hydrofracturing of the pay formations may require further investigations.

(4) Results of the investigation may be used to recommend measures or actions to:

(i) Prevent the development or removal of such minerals from unmined areas to prevent subsidence of the structure.

(ii) Prevent horizontal oil and gas wells from being developed near or underneath the structure or reservoir.

(iii) Preserve or build and maintain adequate support to ensure against future subsidence of the structure’s foundation for mined areas or due to oil or gas extraction.

631.0204 Geologic Investigations for Group B Structure Sites

A. Introduction

(1) These are structures, embankments, and engineering practices that do not classify as Group A, including low-hazard-potential dams with an effective fill height of 35 feet or less.

(2) Other practices included in Group B structures are streambank and shoreline stabilization and other conservation practices, for example: Pond (Code 378), Waste Storage Facility (Code 313), Dike (Code 356), Diversion (Code 362), or Grade Stabilization Structure (Code 410). See https://efotg.sc.egov.usda.gov/#/ (accessed May 2022) for additional information on conservation practice standards.

B. Planning Group B Geologic Investigations

(1) The geologist and design engineer jointly develop a geologic investigation plan that describes what data to collect and how the data will be used to support sound engineering design.

(2) The intensity of subsurface exploration and sampling needed for sites of larger structures in Group B are similar to that for Group A sites. See figure 2-1 for group structure classifications.

(3) General experience in the area, existing geologic information, and the preliminary geologic examination, however, may provide some information so that a less intensive program of subsurface exploration and sampling will suffice for the sites of smaller structures in this group. Specific design elements must be supported by the geological site investigations.

(4) Products and outcomes may include, but are not limited to:

(i) Determine the engineering properties, continuity, relative permeability, and other characteristics of materials beneath the base and abutment area of the embankment, outlet structures, and other structural conservation practices.

(ii) Characterize the stratigraphic and structural discontinuities in the foundation area, such as faults, joints, voids, and fractures. Note the schistosity, slaty cleavage, and bedding characteristics. These observations may be based on outcrops in the area.

(iii) Characterize alluvial materials in the flood plain area for compressibility, permeability, and depth to rock. Evaluate the seepage potential of the permanent pool area if part of the structure's function.

(iv) Determine the extent and character of materials to be excavated for the auxiliary spillway and the character and slope stability of the material in the spillway cut slopes. Determine if rock excavation will be encountered in the auxiliary spillway and estimate rock excavatability.

(v) Locating and determining the depth, thickness, and engineering properties of the earth materials proposed for use as fill. Estimate quantities of available embankment fill. Conduct field crumb testing if dispersible soils are known in the area.

(vi) Determine the depth to groundwater and the seasonal variation of the water table. Evaluate the need for controlling groundwater during construction.

(vii) Complete an SCS-ENG-309, Reservoir Sedimentation Design Summary or equivalent, for a site to determine reservoir sediment storage requirements and the watershed sediment yield.

(viii) Determine if a seismic assessment is needed for the proposed structure.

(5) The report should include a geologic map, cross sections, profiles, fence diagrams, and other illustrations that may be used to represent geologic features.

(6) An engineering geologic map should be drawn to identify and spatially represent zones of geologic material that meet similar engineering performance criteria. The map must include the locations of all measurements, samples, or observations, and the data collected.

C. Test Hole Locations and Depths

(1) All soil, geologic materials, and rock units need to be characterized beneath the footprint of the structure and its features. Borings at all stations within the footprint of the structure should be extended to depths equal to the proposed height of fill associated with the boring or to a firm, limiting layer.

(2) Sufficient borings must be made along the proposed centerline of dams to provide correlation of geologic materials and to define the rock surface profile if possible.

(3) Sufficient borings must be made along the centerline of drop inlets or other conduits to provide reliable correlation of all strata from the riser to the outlet and to a depth equal to the zone of influence of the structure.

(i) Where rock occurs within the zone of influence, the investigation must accurately delineate the rock surface below the centerline of the conduit.

(ii) Normally, bore holes are placed at the riser, at the intersection of the centerlines of the dam and conduit, and at the outlet, with sufficient holes in between to allow reliable correlation.

(4) The depth of investigation under the footprint of the structure should be of sufficient depth to adequately characterize the materials below the structure.

(5) The minimum depth of borings in weak or compressible materials, where the influence of loading by the structure may be significant to depths greater than the height of the dam, will be determined in consultation with the design engineer. Depths of investigation ultimately depend on the significance of the material characteristics and mass characteristics of earth materials to the overall design.

(6) All borings must be sufficiently deep and closely spaced to establish reliable correlation of strata under the entire base of the structure. The number, depth, and the spacing of holes needed depend on the regularity, continuity, and attitude of strata and character of geologic structures.

(7) The investigation of the auxiliary spillway must be of sufficient intensity to determine quantity and character of the materials to be excavated, limits of common and rock excavation, suitability of the excavated material for use in construction, and erodibility of the resulting spillway channel. Each boring must extend to a depth of not less than two feet below the bottom of the proposed auxiliary spillway.

(8) Enough borings must be made in the borrow areas to identify and establish the distribution and thickness of all materials to be used for fill. All borrow area borings should extend at least two feet below the expected depth to which material is to be removed. Determine the depth to groundwater at the time of boring for all borrow area borings.

D. Structures with Permanent Storage

(1) For structures with permanent storage, undisturbed samples of all compressible, fine-grained materials may need to be sampled and tested for consolidation.

(2) Samples for compaction tests must be obtained from the borrow areas and auxiliary spillway areas.

(3) Investigations should also determine if collapsible soils or dissolvable minerals exist in the dam foundation and abutments (e.g., salt and gypsum).

(4) If dispersive soil is a concern in the area, conduct field crumb testing of samples collected from the borrow areas. If crumb test results are positive, additional soil sampling and laboratory testing are required or if dispersive soil is suspected.

E. Structures Subject to Subsidence

(1) The foundation shall provide stable support for the embankment under all saturation and loading conditions and provide sufficient resistance to seepage. The embankment

shall have sufficient strength to remain stable under all saturation and loading conditions by selecting, obtaining, and compacting mineral earth fill materials.

(2) A geologist must determine whether sinkholes, solution cavities, underground mine collapse, or the removal of fluids such as petroleum, water, and natural gas could impact the design, function, and safety of the dams, particularly by abrupt differential settlement.

(3) The geologist must provide recommendations to the design engineer on identified geologic concerns that need to be addressed in the operations and management plan for the structure. If studies indicate that the predicted subsidence cannot be remedied, the site must be abandoned.

F. Waste Storage Structures

(1) NRCS geologists conduct geologic investigations for animal waste management systems so that geologic conditions do not negatively impact the design, construction, and operation of any component. Geologists' involvement depends on the size of the operation and complexity of the geology in the area.

(2) Engineers design animal waste systems to ensure compliance with geologic and groundwater regulations.

(3) See National Engineering Handbook, Part 651 Agricultural Waste Management Field Handbook, Chapter 7 Geologic and Groundwater Considerations, for more guidance on geologic investigation for animal waste systems.

631.0205 General Guidance for Engineering Geologic Investigations for Dams

A. Drilling Methods

(1) Geotechnical borings are typically drilled through consolidated or unconsolidated overburden by sonic drilling, rotary, and auger drilling. Each method has advantages over the other methods under certain conditions.

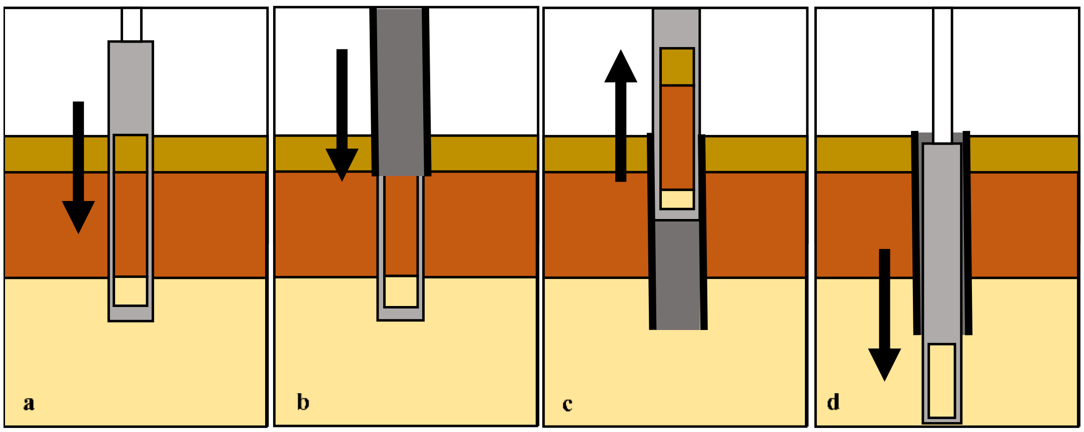
(i) Sonic Drilling

- Sonic drilling, also referred to as rotary vibratory drilling, is capable of drilling through almost any type of geological formation, such as cobbles, boulders, and gravels, sand, clay, and glacial tills. Sonic drilling is a good choice for any geologic material known as challenging or difficult to drill with other conventional methods.
- Drilling fluids are not required, and samples are continuous, giving many advantages over other drilling methods. Sonic drilling is often the preferred method of geotechnical exploration for embankment dams because it is fast, efficient and does not require the use of drilling fluids.
- The primary disadvantage of the sonic method is that samples are generally considered highly disturbed because of the energy used to advance the sampling barrel.
- The method utilizes vibrational energy introduced into the drill rods through a drive motor that rotates eccentric weights at variable rotations per minute (RPMs).
- To advance the boring, the driller controls the frequency of the vibrational energy, the rotation of the drill rods, and the applied downforce.
- Sonic drilling is performed by advancing a sampling barrel into undisturbed earthen material. The standard sampling barrel is 10 feet long, but other lengths may be used. Next, a larger diameter override casing is advanced

over the sample barrel. The override casing is used to stabilize the boring wall and isolate the geologic formation from activities occurring within the borehole. The driller then pulls the sample barrel from the ground and extrudes the sample into a sample bag or plastic sleeve. Another drill rod is added to the existing drill string to advance the sample barrel into deeper, in situ material. The process is then repeated until reaching the final bore hole depth. See figure 2-2.

- For additional discussion on sonic drilling, refer to ASTM D6914.

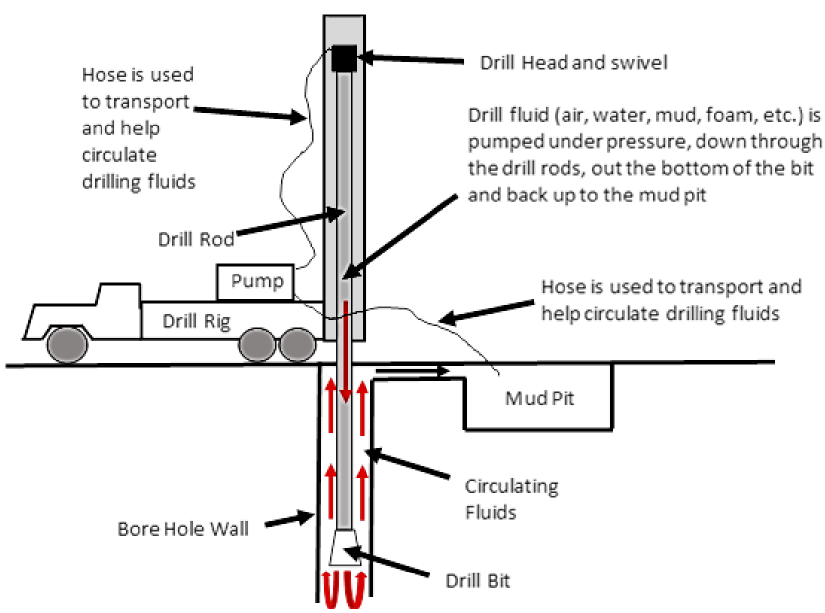
Figure 2-2. Sonic Drilling Process: (a) advancing hole with sampler using high frequency vibration energy; (b) installing override core barrel with casing around the sample barrel; (c) extracting sample barrel from bore hole; and (d) advancing sample core barrel in front of casing and repeating the process until final bore hole depth is reached.



(ii) Mud Rotary

- The mud rotary drilling method, as depicted in figure 2-3, is an open hole drilling method accomplished by applying downforce and rapid rotation of the drill bit and rods, while pumping a bentonite or polymer drilling mud slurry into the hole to stabilize the wall and remove cuttings.

Figure 2-3. Generalized rotary drilling method with drill fluid circulation.

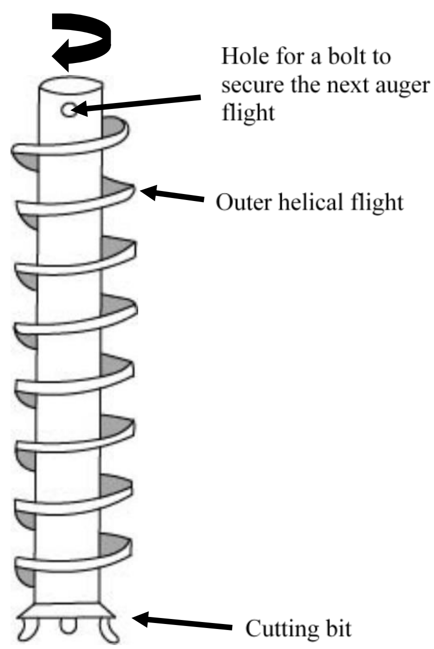


- Drilling mud is circulated down through the drill rods and out the drill bit, where cuttings are picked up and transported upwards in the annulus between the drill stem and bore hole wall, and back into a mud pan or pit at the surface. Drill cuttings settle out of suspension in the pan or pit, and the mud is then recirculated down the hole. In cases where fluids may be lost to the formation, more mud is added as the bore hole advances deeper. Drilling mud is also used to cool the bit, stabilize the bore hole wall, and reduce cross-contamination between aquifers.
- Mud Rotary is a fast and efficient method designed to handle a wide range of geologic conditions. Geologic conditions best suited for mud rotary are rock, consolidated sand, or tight gravel formations where hollow stem augers are ineffective. Conditions not suited for mud rotary are cavernous limestone formations and poorly stabilized cobbly and boulder materials.

(iii) Hollow Stem Auger

- Hollow stem auger drilling is a common method used for soil and very soft to soft rock sampling and groundwater monitoring well installation (see ASTM D6151).
- Hollow stem augers (see figure 2-4) are approximately five-feet-long, manufactured from steel, and have an outer helical flight welded around a hollow shaft. The lead auger is equipped with a cutting head and plug. When the bore hole is advanced, the augers are rotated and advanced using downforce pressure from the drill rig. As each auger is drilled into the ground, another auger is added. Joining the augers results in a continuous flight from the bottom of the bore hole to above ground surface.

Figure 2-4. Hollow stem auger, figure modified from Keely and Boateng 1987.



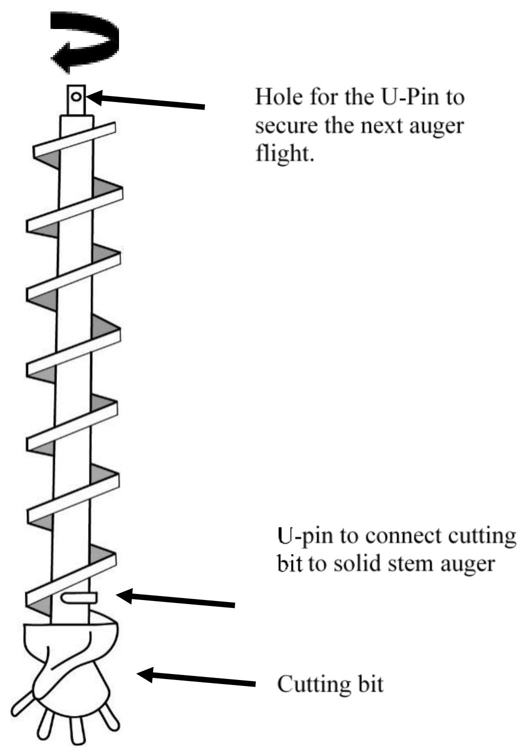
- A pilot bit, bit plug, or center bit assembly is used with a secondary internal rod string to prevent infilling of the auger as the bore hole is advanced. Drill cuttings are pushed upward on the helical flights between the annulus of the auger string and the bore hole wall. When the bore hole reaches the terminal depth, the pilot bit is retracted from the augers, and the driller reverse-drills or rotates the augers in the opposite direction to slowly retract and remove each flight auger.

- When samples are collected, the center bit or bit plug is removed, and a split-spoon sample barrel is lowered into the augers to the bottom of the hole, where a standard penetration test may be performed. The split-spoon is retracted at the end of each sampled run, and the center bit is replaced before advancing the augers to the next sampling interval. Using this sampling method, different soil horizons and rock intervals can be measured and logged with a high degree of accuracy.
- Hollow stem augers can accommodate different testing and sampling methods, including standard penetration and vane shear testing, collecting disturbed and undisturbed samples, and installation of piezometers or monitoring wells.
- When sampling is not required, a pilot bit with plug or center bit assembly is inserted and maintained in the augers to prevent soil from entering the augers.

(iv) Continuous Flight or Solid Stem Auger

- Continuous flight augers (as shown in figure 2-5) are comparable to hollow stem augers, except that the shaft is solid instead of hollow (see ASTM D1452). Bore holes are advanced in a similar manner, using rotation and downward pressure, and each auger section is added to form one continuous flight. To help bring cuttings to the surface and clean out the bore hole, the driller typically increases the rotation speed without downhole pressures at the end of each auger section, before adding the next auger.

Figure 2-5. Flight auger or solid stem auger schematic.



- As drill cuttings are brought to the surface, the materials mix together to form a composite sample. Composite sampling is not as accurate as discreet sampling and may not accurately represent the subsurface materials. For example, non or low cohesive, low-density material, such as a poorly or well graded sand, will likely mix with a higher density material, such as a lean clay, to form a sandy lean clay. This may be problematic for geotechnical or groundwater investigations where precise material classification is important.
- Solid stem augers are typically used to efficiently drill holes for construction or repair purposes rather than geologic exploration.

(v) Direct Push (DP)

- Direct push methods were developed because they produce minimal drilling waste and provides borehole wall protection. Push borings do not use fluids and minimize hydraulic fracturing and groundwater contamination.
- Direct push technology (DPT) (ASTM D6286 2020) was developed specifically for environmental site characterizations. DPT uses the static weight of the rig combined with a drive or hydraulic hammer to advance a soil sampling tool or soil probe. Direct push soil sampling tools do not remove cuttings from the hole but depend on compression of the soil to permit advancement of the tool string. This method consists of forcing a tube into soil materials and withdrawing material retained inside the tube. Continuous drive test holes can be made in clays, silts, and relatively stable materials free from gravel, cobbles, and boulders. The sampler, when withdrawn, acts as a piston in the hole, causing more excessive caving than other methods of boring.

(2) Geotechnical borings drilled through or into rock require special tools and methods. It is common for borings to penetrate overburden by one or more of the three principal methods discussed above. However, when sampling is required in competent rock, the drilling method must be modified, and the tooling changed to allow for boring advancement.

(i) Rock Core Drilling

- Drilling into, through, or collecting samples of competent rock requires specialized tools. The need for these tools should be determined during planning (see ASTM D2113).
- Rock drilling, commonly referred to as core drilling, may be performed in borings that have been advanced through overburden, using mud-rotary or auger drilling methods; but the drilling crew must manually convert the drilling rods and tools to the appropriate equipment.
- Sonic drills are able to penetrate competent rock without changing the drilling tools; however, if significant amounts of rock need to be drilled or representative samples need to be collected, a traditional core drilling rig is more efficient and economical and may be required (see ASTM6914).
- Core drilling requires a steel-cabled wireline winch, sample barrel, and diamond or tungsten core bits.
- Samples are collected in either a single steel tube or barrel, an outer steel barrel with an inner split liner, or an outer steel barrel with two inner steel liners, also known as single, double, or triple tube samplers. The most common sample barrels used are the double or triple tube samplers, or also known as the Denison or triple tube core barrel Denison.
- For more information about these sampling techniques, see NEH Part 631, Chapter 5, Engineering Geology Logging, Sampling, and Testing.

- Before hole advancement begins, the sample barrel is lowered into the drill rods using an overshot tool and steel-cabled wire line, which is attached to the drill rig. An overshot tool, commonly called a “fishing tool,” is used to retrieve a “fish,” the sample barrel, from the bottom of the bore hole. Depending on the hole depth, the driller either lowers the barrel to the bore hole bottom, or the sample barrel is lowered only part way into the bore hole, and the barrel is released from the overshot tool. The tool is retracted to the surface while the barrel drops to the bore hole bottom. The driller then pumps and circulates water into the drill rods until the core barrel locks within the rods.
- As the driller begins coring and advancing the bore hole deeper, the core barrel with inner liner(s) slides over the rock core sample. A 10-foot-long sampled interval can take anywhere from one half hour to sometimes over two hours to drill, depending on the rock hardness. When the sampled interval is completed, the overshot tool is lowered back into the drill rods and locks on top of the sample barrel. The wire line is retracted, pulling the sample barrel to the surface. The core sample remains inside the sample barrel because a split ring core lifter or basket keeps the core in place. When the barrel is removed from the hole, the driller connects one end of the hose to the top of the sample barrel while the other end is attached to the drill rig. Pressurized air and water are used to push the inner liner from the outer steel barrel sample barrel.

B. In Situ Testing

(1) In situ tests are often required to accurately measure the engineering properties of subsurface materials. Careful consideration must be used when planning in situ testing to ensure that the method selected will be sufficient to satisfy the project’s engineering needs and that it is appropriate for local site conditions.

(2) For detailed discussion of in situ testing methods see NEH Part 631 Chapter 5 - Engineering Geology Logging, Sampling and Testing. A list of common methods and their associated ASTM standards are provided below. This list is not comprehensive and many other methods of in situ material testing exist. The geologist should work with engineering staff to ensure appropriate and applicable in situ testing methods are selected. The ASTM standards should be referenced for guidance pertaining to each method’s application, limitations, and procedure.

(i) Standard Penetration Test (SPT) – ASTM D1586/D1586M

(ii) Electronic Friction Cone and Piezocone Penetration Testing (CPT) – ASTM D5778

(iii) Field Vane Shear Test (VST) – ASTM D2573/D2573M

(iv) Flat Plate Dilatometer (DMT) – ASTM D6635

C. Staking and Clearing of Structure Sites

(1) Locations of the proposed centerline of the dam, centerline of the principal spillway, and cross sections of the auxiliary spillway should be staked. Alternate locations for the principal spillway should also be staked.

(2) All grid lines in the borrow area, auxiliary-spillway cross sections, centerline of the principal spillway, and centerline of the dam should be cleared to a width sufficient to provide easy access for the exploration equipment.

(3) Stream crossings must be located with caution to minimize riparian damage and to avoid any wetlands and poorly drained areas.

D. Numbering Test Holes and Logs

(1) Figure 2-6 shows the standard system of numbering test holes and logs used in NRCS investigations. Place the feature (e.g., drill hole, bore hole, test pit, or test trench) in front of the investigation year followed by the hole number (ex. BH21-101, 21-101 or TP21-201).
(i) DH – Drill Hole
(ii) BH – Bore Hole
(iii) TP – Test Pit
(iv) TT – Test Trench
(v) CPT – Cone Penetrometer Test
(2) Assign principal spillway, channel, and auxiliary spillway test holes on the dam centerline, principal spillway, channel, and auxiliary-spillway numbers rather than centerline-of-dam numbers.
(3) Number foundation holes as “other” at the base of the dam, not in the immediate vicinity of the dam centerline, appurtenances, or on the embankment.

Figure 2-6. Test Hole Numbering System.

Location	Test Hole Numbers
Centerline of dam and abutments	1 - 99
Borrow area	101-199
Auxiliary spillway	201-299
Centerline of principal spillway	301-399
Stream channel	401-499
Relief wells	501-599
Bore holes on embankment, offset from centerline	601-699
Other	701-799, etc.

E. Determining Location and Depth of Proposed Test Holes

(1) Exploratory borings are made along the centerline of the dam, along the centerline of the outlet structure, in the spillway area, and in the borrow areas.
(2) Additional exploratory borings are needed if relief wells or foundation drains may be required, or if special information is needed because of site conditions encountered during the investigation.

F. Foundation Test Holes

(1) Foundation investigations must determine:
(i) If the site will provide a stable vertical and horizontal support for the structure.
(ii) If subsurface strata have enough strength to prevent crushing, excessive consolidation, and plastic flow.
(iii) If water movement through the foundation or abutments will cause piping, detrimental uplift pressure, or excessive water loss.
(2) Conditions that must be recognized and located include:
(i) Nature, extent, and sequence of strata
(ii) Soils with dispersive clays
(iii) Soluble salts
(iv) Liquefiable soils
(v) Aquifers (confined, unconfined, perched)

(vi) Weak bedding planes, joints, faults, voids, or other structural weaknesses in the underlying formations
(vii) Collapsible soils
(viii) Expansive clays
(ix) Permafrost
(x) Karst

(3) The spacing and number of test holes needed along the structure centerline or beneath the proposed base depend principally on the complexity of the geology. Some of the more important factors are character and continuity of the beds, attitude of the strata, and presence or absence of joints or faults. Depth, thickness, sequence, extent, and continuity of the different earth materials must be determined.
(4) To determine site conditions, locate one test hole on the floodplain near each abutment and one on the proposed principal spillway centerline. Place additional holes between these locations, as needed, to establish good correlation of strata.
(5) Locate test holes at the riser and outlet structure of the principal spillway. Additional holes can be drilled in between as needed to establish good correlation of strata.
(6) Locate at least one test hole in each abandoned stream channel that crosses the centerline.
(7) At least one test hole is usually required in each of the abutments. Additional test holes may be required to adequately define the geologic conditions.
(8) Conduct enough subsurface investigations to establish continuity of strata and potentially hazardous or defective zones throughout the area underlying the base of the proposed structure. Identify pervious, unstable, or compressible materials to a depth equal to at least the height of the structure, unless impervious and indurated, virtually incompressible material is encountered.

G. Foundation Loading Strength, Presumptive Bearing Values, and Test Hole Depths

(1) Depth of exploration depends on the character of material and on the combined pressure exerted by overburden and embankment materials.
(2) Figure 2-7 shows the presumptive bearing values of various unconfined materials for different consistencies and relative densities. These values are approximate loads for soil materials without excessive settlement. Note that a given amount of settlement per unit thickness may be of minor significance for a thin layer but may be excessive for a thick stratum.

Figure 2-7. Presumptive bearing values of soils (approximate maximum safe-load values) as related to the Unified Soil Classification System.

Noncohesive Materials									
Relative Density[1]	**N[2] (blows/ft)**	**GW**	**GP**	**SW**	**SP**	**GM**	**GC**	**SM**	**ML**
Tons per square foot									
Very loose	<4	--	--	0.50	0.50	0.25	0.25	<0.25	--
Loose	4–10	1.75	1.75	1.00	1.00	0.50	1.25	0.75	0.25
Medium or firm	10–30	3.50	3.25	2.25	2.00	1.40	2.40	1.75	1.00
Dense or compact	30–50	5.25	5.00	3.75	2.25	2.80	3.50	2.50	1.75
Very dense or very compact	50+	6.00	5.75	4.50	3.25	3.50	6.25	3.00	2.00
Cohesive Materials									
Consistency[1]	**N[3] (blows/ft)**	**SM**	**SC**	**ML**	**CL**	**OL**	**MH**	**CH**	**OH**
Tons per square foot									
Very soft	<2	0.25	0.25	--	0.25	--	--	--	--
Soft	2–4	0.50	0.50	0.25	0.50	--	0.25	0.25	--
Medium	4–8	0.75	1.00	0.75	1.00	0.25	1.00	1.00	0.25
Stiff	8–15	1.50	2.25	1.75	2.25	1.00	2.25	1.50	1.00
Very stiff	15–30	2.00	2.75	2.00	2.75	1.50	2.75	1.75	1.25
Hard	30+	2.50	3.25	2.50	3.25	2.00	3.25	2.25	1.50

Note: 1) These are approximate values to be used only to guide investigation needs. Values are not for design criteria. A Safety Factor of 3 is built into these values.
2) Relative density and consistency as related to standard penetration test. Blow counts represent uncorrected field values.
3) Consistency values for the standard penetration test for cohesive soils.
4) From Terzaghi and Peck 1948

(3) The presumptive bearing capacity values are the same as allowable bearing capacity values. These values incorporate a Factor of Safety of 3 relative to ultimate bearing capacity values. The ultimate bearing capacity value divided by three equals the allowable bearing capacity value.

(4) Estimates of consistency and relative density must be made from examination of representative samples, standard penetration test blow counts, drilling characteristics, or estimates of the density and void ratio of the material.

(5) See figure 2-8 for the approximate vertical stress values for earthfill structures weighing 100 pounds per cubic foot. An example of how to use figures 2-7 and 2-8 to determine appropriate depths of test holes follows.

(i) A test hole has been drilled to the minimum depth of 50 feet in the foundation for a structure designed to be 50 feet high. The test hole is still in compressible materials. The approximate vertical stress at this depth from a 50-foot structure is l.9 tons per square foot (figure 2-8). The material at the bottom of the hole is stiff, inorganic plastic clay (CH). Figure 2-7 shows that stiff CH has a presumptive bearing value of 1.5 tons per square foot. This indicates that the formation is subject to deformation under the proposed load and that exploration must continue to a greater depth until the vertical stress is equal to or less than the safe load value. For this example, the test hole needs to be extended to a depth of 85 feet, where the vertical stress is equal to the presumptive bearing value of the encountered material.

(ii) The purpose is to quickly determine how deep to drill or investigate into the foundation of a project.
(iii) The method assumes a vertical homogenous foundation of infinity.
(iv) Figure 2.8 assumes 2.5H:1V side slopes.

H. Principal Spillway Test Holes

(1) Complete information on the strata underlying the outlet structure is needed for its design. Address the potential for differential settlement, which may result in cracking. If the outlet conduit is to be located on or near rock with an irregular surface, the profile of the rock surface must be accurately defined.
(i) The number of test holes required for this purpose depends on the configuration of the rock. If the rock surface is undulating, numerous test holes may be required so that the needed depth of cradle and the treatment of the foundation can be determined. Where feasible, use trenching to expose and characterize the nature of the soil/rock interface.
(ii) Test holes are required at the proposed riser location, at the downstream toe of the structure, and at the downstream end of the outlet conduit.
(iii) For other types of outlets, exploration requirements vary widely from site to site, but test holes must be adequate to provide the information necessary for the design bearing strength and to assess the potential for sliding.

(2) The minimum depth of test holes along the outlet centerline must equal the height of the proposed fill over the outlet conduit, or 12 feet, whichever is greater, unless unweathered rock is encountered. The minimum hole depth below the riser must equal the difference in elevation between the top of the riser and the natural ground line or 12 feet, whichever is greater.

Figure 2-8. Approximate Vertical Stress Values of Earthfill Structures.

Height of Dam (feet)	Depth (feet)																								
	5	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**	**55**	**60**	**65**	**70**	**75**	**80**	**85**	**90**	**95**	**100**	**110**	**120**	**130**	**140**	**150**
Tons per Square Foot																									
5	0.2	0.1	0.1	0.1	0.1																				
10	0.5	0.4	0.3	0.3	0.2	0.2																			
15	0.7	0.6	0.6	0.5	0.5	0.4	0.4	0.3																	
20	1.0	0.9	0.8	0.8	0.7	0.7	0.6	0.6	0.5	0.5	0.5	0.4													
25		1.2	1.1	1.1	1.0	0.9	0.9	0.8	0.8	0.7	0.7	0.6	0.6	0.6	0.6										
30			1.4	1.3	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.6							
35					1.5	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7				
40					1.7	1.7	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.8	0.8	
45					2.0	1.9	1.9	1.8	1.7	1.7	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.3	1.2	1.2	1.1	1.1	1.0	0.9	0.9
50						2.2	2.1	2.0	2.0	1.9	1.8	1.8	1.7	1.7	1.6	1.6	1.5	1.5	1.4	1.4	1.4	1.3	1.3	1.2	1.2
55							2.4	2.3	2.2	2.2	2.1	2.0	2.0	1.9	1.9	1.8	1.8	1.7	1.6	1.6	1.5	1.5	1.4	1.3	1.3
60								2.6	2.5	2.4	2.4	2.3	2.2	2.2	2.1	2.0	2.0	2.0	1.9	1.9	1.8	1.7	1.6	1.5	1.5
65									2.8	2.7	2.6	2.5	2.5	2.4	2.4	2.4	2.3	2.2	2.2	2.1	2.1	2.0	1.9	1.7	1.7
70									3.0	2.9	2.9	2.8	2.7	2.7	2.6	2.6	2.6	2.5	2.4	2.3	2.3	2.2	2.1	2.0	1.9
75										3.2	3.1	3.1	3.0	2.9	2.9	2.9	2.8	2.7	2.7	2.6	2.6	2.5	2.4	2.2	1.9
80											3.4	3.3	3.2	3.2	3.1	3.1	3.1	3.0	2.9	2.9	2.8	2.7	2.6	2.4	2.3
85												3.6	3.5	3.4	3.4	3.4	3.3	3.2	3.1	3.1	3.0	2.8	2.7	2.6	2.6
90												3.9	3.8	3.7	3.6	3.6	3.6	3.4	3.3	3.3	3.2	3.1	3.0	2.9	2.8
95													4.0	4.0	3.9	3.9	3.8	3.7	3.6	3.6	3.4	3.3	3.2	3.1	3.0
100													4.3	4.2	4.2	4.2	4.1	3.9	3.8	3.8	3.7	3.6	3.5	3.4	3.3

Notes: 1) Do not use for design purposes.
2) Vertical stress values are approximate numbers for earthfill structures weighing 100 pounds per cubic foot.
3) For embankment slopes of 2.5H:1V.
4) Jurgenson, Leo, 1934, “The application of Theories of Elasticity and Plasticity to Foundation Problems.”
5) Compacted embankment fill may have a greater unit weight than 100 pounds per cubic foot.
6) Figure 2-8 does not apply to problematic soils such as collapsible soils.

I. Auxiliary Spillway Holes

(1) Determine stability and erodibility of spillway materials and provide adequate information on the extent and volume of the various types of material to be excavated and on the suitability of the excavated material for use in construction.

(2) The SITES computer program, "Earthen/Vegetated Auxiliary Spillway Erosion Prediction for Dams," is used for determining spillway design erodibility. The program assists the design engineer in the hydraulic and hydrologic analysis of dams.

(i) NRCS geologists provide geologic information in the evaluation of auxiliary spillway performance for design and rehabilitation purposes.

- The geologist plans an investigation of the auxiliary spillway with the design engineer to obtain geologic material information.
- Layers of the auxiliary spillway are developed for a profile of the auxiliary spillway.
- Drilling and sampling are usually involved to provide a headcut erodibility index (K_h) of each layer to the design engineer.
- One drill hole is advanced to the valley floor. See SITES User Guide for additional information and requirements.
- Instructions for developing the K_h values are available in NEH, Part 628, Chapter 52 Field Guide Procedures for the Headcut Erodibility Index.

(ii) The geologist and design engineer work together to develop a profile of earth materials in the auxiliary spillway for the SITES program.

(iii) The SITES program allows the user to then test alternatives to provide satisfactory proportioning of flood storage and outflow.

(iv) The program incorporates USDA-Agricultural Research Service (ARS) erosion technology for the integrity and stability of earth spillways.

(v) Sampling and testing should be consistent with the requirements of this analytical tool, downloadable at https://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/national/water/manage/hydrology/?cid=stelprdb1042517, (accessed May 2022).

(3) Develop a series of geologic cross sections at right angles to the centerline of the spillway, if conditions are highly variable or if long spillway sections are planned.

(i) Initially, locate one cross section approximately at the control section, one in the outlet section, and one in the inlet section of the spillway.

(ii) Locate additional cross sections as needed for correlation, to locate contacts, or to obtain additional needed data.

(iii) Locate test holes on each cross section at the centerline and at the boundaries of the spillway.

(4) Detailed investigations are imperative and required to estimate rock quantities for excavation, ripping, or blasting. These methods usually require drilling equipment, even where delineation of the rock surface has been accomplished by using a bulldozer or backhoe.

(i) Where deep spillway cuts are planned, additional test holes may be needed to determine the character of the material and water table in the sides of the cut.

(ii) Where consolidated rock is encountered in the spillway, carefully delineate the rock surface, which may require more test holes and cross sections.

(iii) Drill auxiliary spillway investigation borings to a depth of no less than two feet below the bottom of the proposed auxiliary spillway.

(5) Material factors influence the method and cost of excavation. Under some combinations of these conditions, rock can be ripped and removed. Other

combinations may require special equipment or blasting. Carefully log materials before excavation, noting any structural features such as:
(i) Rock material strength
(ii) Weathering
(iii) Density of fractures (crushed, intensely fractured, etc.)
(iv) Thickness of beds
(v) Attitude, character, and condition of bedding and joint planes (type, shape, roughness, and type of infill such as clay, calcite, etc.)
(vi) Schistosity
(vii) Cleavage
(viii) Flow banding
(ix) Cavities and solution channels, and strength, degree, and kind of cementation.

J. Borrow Area Test Holes

(1) General
(i) Proposed borrow areas are investigated to identify and classify the materials for quantity, location, and suitability for use in construction.
(ii) The geologist should locate 50 percent more borrow material than is need for construction, to account for compaction, spillage, and unsuitable determinations.
(iii) Follow material sampling guidelines for borrow area laboratory testing. See Section 631.0207 of this chapter or NEH, Part 631, Chapter 5 – Engineering Geology Logging, Sampling, and Testing.
(iv) Conduct crumb tests in the field to assess the potential for dispersive clays, as needed. (ASTM D6572 2021).
(2) Test Hole Depth
(i) Extend all borings at least five feet below the expected depth of removal of material, unless consolidated material is encountered that is not suitable for use. Three test holes per acre are typically adequate to determine borrow area suitability.
(ii) Determine location and approximate extent of undesirable materials. Record depth to groundwater, if reached, and note if groundwater was not observed.
(iii) Record soil redoximorphic features indicating depth of seasonal high-water table, if present.

K. Reservoir-Basin Test Holes

(1) General
(i) Subsurface exploration may also be required in reservoir basins, if water-holding is to be a function, and in the general area of the structure site.
(ii) The pool area is sometimes used as a borrow source. If the pool area is investigated for a borrow source, these test holes can be evaluated for seepage.
(2) Concerns
(i) The location, number, and depth of these test holes depend on the specific problems to be assessed or solved.
(ii) If cavernous or permeable strata are encountered that may adversely influence the functioning or stability of the structure, further investigations are needed.
(iii) Sandy layers or strata upstream of the centerline and in the pool areas may need to be investigated for water holding ability or seepage concerns.
(iv) Cultural resources, wetlands, and endangered species must be respected while conducting field activities.

L. Foundation-Drain and Relief-Well Test Holes

(1) General

(i) If permeable materials are encountered along the centerline of the proposed structure, foundation drains, relief wells, or both may be needed, and their locations investigated.

(ii) Relief wells are usually located at or near the downstream toe of a structure.

(iii) Foundation drains may be located between the centerline and the downstream toe, depending on the specific problems and conditions. Foundation drainage methods or relief wells may be necessary to control uplift pressure, to facilitate consolidation, or to prevent piping.

(iv) Deep foundation drains, consisting of trenches backfilled with properly designed filter materials, can be used as an economical alternative to relief wells. This method is suited to stratified or lenticular materials and where aquifers can be tapped feasibly by excavation.

(2) Investigation Intensity

(i) The geologist must recognize permeable layers or strata and inform the design engineer with concerns.

(ii) Exploration must be extended downstream from the centerline to determine the extent and continuity of the permeable substrata.

M. Stream Channel Test Holes

(1) General

(i) If the stream channel contains boulders, roots, debris, and organic matter, it may be necessary to remove these materials from beneath the structure as "special stream channel excavation."

(ii) Usually, excavation is required to prevent leakage through the foundation, from the upstream toe of the structure to a point two-thirds of the distance from the centerline to the downstream toe. Channel investigations provide information on the depth, nature, quantity, and location of the deposits to be removed.

(2) Source of Materials

(i) The stream channel may be a local source of sand or gravel for use in foundation drains, filter blankets, and roadways.

(ii) The geologist should carefully log, sample, and compute quantities of these materials and their potential suitability, including anticipated washing and screening requirements.

N. Other Investigations

(1) Test holes may be needed at other locations to determine the continuity of materials upstream and downstream throughout the foundation and reservoir area. Information may be needed on the depth, nature, quantity, location, and extent of undesirable deposits within the foundation area, such as organic soils, liquefiable soils, very soft silts and clays, and boulders.

(2) Structural features such as faults and contacts may need to be accurately located and their attitude mapped throughout the site area.

O. Decommissioning Test Holes

(1) Any test hole, test pit or trench left open shall be secured to eliminate hazards to people, animals, equipment and prevent groundwater contamination from surface water flow. Test pits and trenches must be filled to eliminate hazards to people,

animals, equipment, and to prevent groundwater contamination. Bore holes must be decommissioned in accordance with all local, State, tribal, and federal law.

(2) Boreholes are commonly backfilled with a slurry mix of cement and bentonite that is placed through tremie pipe from the bottom of the boring to the surface. Care and expertise must be practiced when designing mixes for Group A structures. ASTM D5299 (Standard Guide for Decommissioning of Groundwater Wells, Vadose Zone Monitoring Devices, Bore holes, and Other Devices for Environmental Activities) covers procedures to decommission bore holes and provides additional guidance.

631.0206 Outline of Geologic Investigation Report

A. Introduction

(1) The geologic investigation report must clearly document investigation methods and information obtained, including copies of all field logs, maps, cross-sections, and conclusions.

(2) The following outline must be used as a guide for a detailed geologic investigation report. The outline may be modified for the level and intensity of the subject report for a reconnaissance or preliminary level investigation.

B. Geologic Investigation Report Outline

(1) General
- (i) Exploration date
- (ii) Personnel engaged in exploration
- (iii) Watershed (name and location)
- (iv) Site number
- (v) Site group and structure class
- (vi) Purpose (flood control, water supply, irrigation, etc.)
- (vii) Location
  - Lat/Long
  - Public Land Survey location
  - State Plane or UTM coordinates
- (viii) Equipment used (type, size, makes, models, etc.)

(2) Site data
- (i) Size of drainage area above site (square miles and acres)
- (ii) Maximum pool depths and preliminary elevations if known
  - Top of dam
  - Flood pool
  - Sediment pool
  - Other pools
- (iii) Structure information
  - Maximum height
  - Length of embankment
  - Location of spillway
  - Volume of fill

(3) Special methods used (if applicable)
- (i) In situ testing
- (ii) Geophysical equipment

(4) Surface geology and physiography
- (i) Physiographic area
- (ii) Topography

- Steepness of valley slopes
- Width of floodplain

(5) Geologic formations and surficial deposits
  (i) Names and ages (e.g., Jordan member, Trempealeau Formation, Cambrian Age; Illinoisan till; Recent alluvium)
  (ii) Formation description
  (iii) Topographic position

(6) Geologic structure of area
  (i) Regional and local dip and strike
  (ii) Faults, joints, unconformities, etc.

(7) Evidence of landslides and potential for landslides
  (i) Location
  (ii) Geologic formation if known

(8) Location and evidence of seepage, springs, etc.

(9) Sediment and erosion
  (i) Gross erosion, present and future, by source
  (ii) Delivery rates
  (iii) Sediment yield (see ASTM D6145)
  (iv) Storage requirements and distribution
  (v) Complete and attach the SCS-ENG-309 as needed

(10) Downstream channel stability
  (i) Present channel conditions
  (ii) Anticipated effects of the proposed structure

(11) Subsurface geology
  (i) Embankment foundation
  - Location and types of test holes and number of samples of each type collected
  - Depth, thickness, and description of pervious or low-volume-weight strata
  - Give detailed data on aquifers or water-bearing zones
  - Depth and description of firm foundation materials
  - Location, depth, thickness, and description of any questionable or problematic materials
  - Description of abutment materials, including depth and thickness of pervious layers or aquifers
  - Rock Quality Designation (RQD) (see ASTM D6032)
  - Location, attitude, pattern, and other pertinent data on any geologic structural features such as joints, bedding planes, faults, and schistosity
  - Location of water table and estimated rate of recharge (high, medium, low)
  - Permeability of abutments

  (ii) Centerline of outlet structure
  - Location and type of test holes and number of samples of each type collected
  - Depth, thickness, and description of pervious or low-volume-weight strata
  - Depth and description of firm foundation materials
  - Location, depth, thickness, and description of any questionable materials
  - Location, attitude, pattern, and other pertinent data on any geologic structural features such as joints, bedding planes, faults, and schistosity
  - Location of water table and estimated rate of recharge (high, medium, low)

  (iii) Auxiliary spillway and other open outlets
  - Location and types of test holes and number of samples of each type collected

- Location, depth, thickness, and description of materials encountered, including:
  - Hard rock or unconsolidated material to be removed and volume estimated of each
  - Location, attitude, pattern, and other pertinent data on any geologic structural features such as joints, bedding planes, faults, and schistosity
  - Material at base of excavation
  - Any questionable material
  - Field dispersion test results if conducted
- Attached SITES profile of geologic layers and the corresponding K_h values

(iv) Borrow area(s)

- Location of test holes and number and type of samples collected
- Location, depth, thickness, description, and estimated quantities of various types of material
- Field dispersion test results if conducted
- Seepage evaluation for borrow sources in the reservoir pool area

(v) Relief-well and foundation-drain explorations

- Location of test holes and number and type of samples collected
- Description of materials, including location, depth, thickness, and description of pervious strata

(vi) Other explorations

- Purpose or concern
- Equipment used and results
- Location of test holes and number and types of samples collected
- Description of materials
- Existing embankment materials

(vii) Water supply

- Available sources (farm ponds, rivers, wells, municipal, etc.) and quantity
- Quality of available water. If questionable, what samples were taken for analysis?

(viii) Construction materials (other than earthfill)

- Sources of materials for concrete aggregate, riprap, impervious blanket, wells, and drains
- Description, location, and estimated quantities of materials available

(12) Logs. Attach completed copies of Form SCS-533 or equivalent https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs144p2_064870.pdf (accessed May 2022)

(13) Interpretations and conclusions ("For in-Service use only")

(i) Interpretations

- Interpretations of geologic conditions at the site
- Possible relation of conditions to design, construction, and operation of structure

(ii) Conclusions. Geologic conditions that require special consideration in design and construction

(iii) Attach completed copies of NRCS–ENG–376A, –376B and –376C https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs144p2_064928.pdf

(iv) Attach completed copies of Forms SCS-35A, -35B, and -35C or their equivalent

C. Report Supplement for In-Service Use Only

(1) General
- (i) Record only basic data and facts in the geologic report. This report is made available for inspection by non-NRCS interests on request.
- (ii) The report contains a section on interpretations and conclusions and should be labeled “For In-Service Use Only.”

(2) Distribution
- (i) Copies of the completed plan and profile sheets for geologic investigations must accompany the report supplement. Geologic conditions must be documented for the site and their possible relation to the engineering feasibility of the site and to the design, construction, and operation of the proposed structure.
- (ii) Problems related to the geologic conditions must be clearly articulated, such as foundation weakness, seepage problems, excess groundwater during construction, difficulties of excavation, spillway problems, or problems concerning available borrow materials.

(3) Recommendations
- (i) The geologist should make specific recommendations in the report for alternative methods to address problems posed by the geologic conditions of the site.
- (ii) Recommendations might include suggestions to the design engineer on such items as alternate locations for the principal spillway, auxiliary spillways, depth of core trench, and depth of keyways into abutments.
- (iii) The need for an impervious blanket, grouting, cutoff trench, or other control of excessive water loss may also be indicated.
- (iv) Special problems should be highlighted that may arise during construction of the structure, such as difficulties in excavation and suitability of the excavated rock for use as riprap, sources of concrete aggregate, and recommendations on sources of water for construction.

631.0207 Minimum Requirements for Sampling and Testing of Structure Sites

A. Introduction

(1) General
- (i) The intensity of sampling needed, like the intensity of site investigations, varies with design requirements. The minimum sampling and testing needs are identified by the geologist and design engineer, based on the complexity of the geology of the site, the existence of geologic hazards for which specific design elements will be needed, and the hazard classification of the structure.
- (ii) In order for a laboratory to classify soil accurately, the sample must be large enough to contain a representative percentage of each particle size. Recommended minimum sample sizes based on particle size are given in figure 2-9.

Figure 2-9. Minimum Sample Size

Maximum particle size (sieve opening)	Minimum sample size
4.75 mm (No. 4)	110 g (0.25 lb)
9.5 mm (3/8 in)	220 g (0.5 lb)
19 mm (3/4 in)	1 kg (2.2 lb)
38 mm (1-1/2 in)	8 kg (18 lb)
75 mm (3 in)	60 kg (132 lb)

After NEH Part 631, Chapter 5.

(2) Samplers
  (i) Some samplers used for logging test holes furnish small, disturbed samples that are adequate for laboratory testing; others do not.
  (ii) Undisturbed samples and larger or additional small, disturbed samples of unconsolidated materials may be required for soil mechanics testing and analyses (see ASTM D1587).
  (iii) See NEH Part 631, Chapter 5, Engineering Geology, Logging, Sampling and Testing for a description of the various sampling methods, equipment, and sample size requirements.

B. Sampling Group A Structure Sites

(1) General
  (i) Disturbed and undisturbed samples are taken of representative unconsolidated materials at the site.
  (ii) Rock core samples may also be collected as well. Representative samples for classification purposes should be taken of all types of materials in the borrow areas, foundation, relief-well, and spillway sections.
  (iii) Samples for compaction and shear tests should be taken from the borrow areas and auxiliary spillway areas.

(2) Undisturbed samples
  (i) Undisturbed samples are required for shear tests from all strata of fine-grained soils of questionable stability in the foundation within a depth equivalent to one-half the height of the structure.
  (ii) Undisturbed samples are required for consolidation tests of all fine-grained materials of questionable stability within a depth equivalent to the maximum height of the structure. Where compressible materials extend to depths greater than the height of the structure, sampling depths must be increased.

(3) Questionable materials
  (i) Sample low shear strength materials, such as soft clays and soft silts, in the foundations of all structures. The extent of soft and weak materials should be determined for all types of geotechnical analyses.
  (ii) Collect and analyze samples of water supplies intended for construction of the embankment or concrete appurtenances, if high concentrations of salts (particularly sulfates and alkalis) or acids are suspected.
  (iii) Secure samples of materials proposed for stabilization by soil cement or chemical methods.
  (iv) Sample reservoir bottom and abutment materials to determine reservoir-sealing requirements if storage (other than sediment-pool storage) is part of the design and if moderate or serious leakage is suspected.

C. Sampling Group B Structure Sites

(1) General
  (i) Collect representative samples for classification purposes of all material types in the borrow areas, auxiliary spillway, foundation, and relief-well sections.
  (ii) Collect samples for compaction from the borrow and auxiliary spillway areas.

(2) Questionable materials and undisturbed samples
  (i) Undisturbed samples for shear tests are required if questionable materials of low shear strength are encountered, such as soft clays and silts.
  (ii) Undisturbed samples may not be required for shear tests of foundation materials of Group B structures. The design engineer should be consulted as the geologic investigation progresses, if questionable material is encountered.

(iii) Samples for consolidation tests are required under the same conditions as those outlined for shear tests. If compressible materials are encountered, samples may be needed from depths greater than the equivalent height of the structure.
(iv) The sampling requirements for permeability tests, water analyses, soil cement tests, and reservoir-sealing tests for structure sites in Group B are the same as for structure sites in Group A.

631.0208 Geologic Investigation During Project Implementation and Construction (As-Built)

A. General

(1) Geologic materials become exposed during excavation of pipeline trenches, structure foundations, core trenches, auxiliary spillway cuts, and borrow areas.
(2) If an unanticipated geologic condition that requires design modification is encountered during construction of any NRCS project, structure, practice, or component, the responsible field person must notify the State Conservation Engineer (SCE) as soon as possible.

B. Additional Technical Support

(1) The SCE determines the need for and secures the services of an experienced geologist to conduct a site assessment of the geologic condition and to provide interpretations and technical support for design or installation changes.
(2) Additional sampling and testing are required if fill materials change.
(3) Documentation may also include revised geologic maps, cross sections prepared in earlier investigations, photos, video recordings, or supplemental topographic or global positioning system (GPS) surveys.
(4) Additional surveys of the pool area are needed if borrow materials are removed for embankment fill. This documents storage volume changes for the structure.

631.0209 Investigations for Repair, Rehabilitation, and Decommissioning of Structures

A. General

(1) Engineering structures and practices requiring repair or rehabilitation may need additional geologic information due to advancements in technology, changes in criteria, land use changes, or deterioration from age.
(2) Geologists may participate on committees for investigations of problems, failures, and deficiencies of structures and practices as described in NEM, Title 210, Part 504 – Special Investigations, Studies, and Reports.
(3) NRCS geologists may provide technical assistance by conducting investigations for the Emergency Watershed Protection (EWP) program.
(4) Additional investigations may be required, beyond the scope of the original investigations, due to design changes required for a higher hazard class, changes in criteria or standards, anticipated changes in function, or other watershed alterations.

B. Rehabilitation of Structures

(1) Geologists and design engineers work together in the rehabilitation of watershed structures. The geologist should be involved with the geologic investigation portion of the statement of work and plan of work for the structure.

(2) The geologist should have input in location of holes, number of holes, type of samples, and equipment used for the project.
(3) The geologist should be onsite observing for part or all of the geotechnical investigation. Drill holes in the embankment should be observed by the geologist. If drilling fluids are required, they must be used cautiously and with care. Fluid weight and viscosity should be designed and monitored so that risk to the structure is minimized. Drilling fluids should only be used in an existing embankment when absolutely necessary. Drilling methods that allow dry advancement of the test hole are preferred because they reduce the risk of damage to the structure.
(4) The geologist should be involved in reviewing of indefinite delivery/indefinite quantity (IDIQ) proposals for geotechnical investigations. Reports produced by outside entities for the rehabilitation of NRCS structures must be reviewed by the geologist.

C. Decommissioning of Structures

(1) Engineering structures and practices selected for decommissioning may involve the complete or partial removal of a structure or a change in its original design function.
(2) Investigations of impoundment structures and practices selected for decommissioning must address the quantity, location, type, quality, and fate of deposited sediment that will be affected by the decommissioning project, either by capping, exposure to erosion and downstream transport, or sluicing, dredging, or excavation.
(3) Assessment must also include the potential effects of changes in the sediment-water balance on streams upstream and downstream from the reservoir sediment pool area.

631.0210 Geology and Geotechnical Considerations for TR-60 Dams

A. General

(1) Investigate site geologic and geotechnical conditions in a manner that adequately examines embankments, spillways, abutments, borrow areas, and foundations to enable adequate evaluation of all design conditions. For TR-60 dams, site conditions and dam features that require special attention include, but are not limited to, geologic conditions discussed below.
(2) Provide appropriate levels of intensity and detail of these investigations for the hazard classification of dam, complexity of site geology, and the data needed for the dam's design.
(3) The design engineer (acting as team leader), geotechnical engineer, geologist, and other disciplines requiring geotechnical data, must jointly complete a geotechnical investigation plan prior to initiating geologic investigations. This plan must provide the basis for geologic investigations and must include the sampling and testing required for:
    (i) Addressing site geologic conditions.
    (ii) Specific requirements of the anticipated design at the stage of the subject investigation.
    (iii) General requirements of TR-60 (Technical Release 210-60 Earth Dams and Reservoirs, March 2019: PART 4 – Geologic & Geotechnical Considerations).
(4) Keep an updated testing program in alignment with the geotechnical investigation plan and provide the testing program with samples submitted for testing. Complete a draft report of the geologic investigation and provide for use prior to preparing the soil mechanics report. At a minimum, the draft must include a description of key geotechnical and geologic issues at the site, the anticipated design, preliminary

profiles and cross sections, and preliminary boring logs with field classifications and in situ test results.

(5) Complete the final report of geologic investigations, including field and laboratory classifications, in final format for use in preparing the design.

(6) NEM-531, “Geology,” provides NRCS policy for geologic investigations.

(7) 210-NEH Part 631, “Geology,” establishes the general requirements, procedures, and criteria for geologic investigations.

B. Soils with Dispersive Clays

(1) Soils containing dispersive clays are extremely erodible. Dams constructed using dispersive clays are vulnerable to internal erosion failures and require special design considerations.

(2) Geologic investigations for soils containing dispersive clays require that soil samples be preserved and transported in sealed, moisture proof containers. Waterproof plastic bags, plastic buckets, and glass and plastic jars may be used as sample containers. Obtain many discrete samples and preserve the natural water content for testing at a soil mechanics laboratory. (ASTM D6572 2022).

C. Karst

(1) Karst terrain requires detailed evaluation of potential subsidence, seepage, and leakage in the dam foundation and reservoir floor. Thoroughly evaluate these issues because they have significant impact on the design, construction, cost, performance, and safety of the structure.

(2) Multipurpose structures with permanent water storage in karst areas are especially critical. The geotechnical investigation must determine, and the report clearly state, if there are any foundation materials with dissolution potential.

D. Collapsible Soils

(1) Evaluate the potential of moisture deficient, low density, unconsolidated materials to collapse on saturation or wetting. NRCS typically encounters collapsible soils in arid and semiarid areas.

(2) Collapsible materials are often associated with deposits such as alluvial fans, terraces, and aeolian soils. If the potential for collapsible soils exists, perform an extensive site investigation and testing to provide quantitative information for design and construction. Obtain and test undisturbed samples that are representative of the collapsible material.

E. Liquefaction Potential

(1) Soil liquefaction typically occurs in recent deposits of loose sand and silty sand located below the water table; however, gravels and low plasticity silts may also liquefy.

(2) Assess groundwater conditions and the occurrence and extent of potentially liquefiable soils that could lose strength under the earthquake shaking considered at a site. Characterize other soils that could undergo loss of strength resulting from earthquake shaking, including sensitive clays and plastic silts that are potentially susceptible to cyclic softening, and collapsible weakly cemented soils.

(3) When developing a subsurface investigation plan, the geologist and geotechnical engineer must consider identifying and locating all layers of potentially liquefiable soils to provide adequate data to analyze the potential significant loss of strength under earthquake shaking and loading.

F. Auxiliary Spillways

(1) Evaluate all earth materials beneath a vegetated or earth auxiliary spillway down to the elevation of the downstream floodplain or valley floor in enough detail to determine excavation requirements, suitability of spillway excavation for embankment fill, and to determine stability and integrity of the spillway.
(2) Highly erodible material, such as dispersive clays, silts and sands, and material that will require special processing for use as fill, require more detailed investigation.
(3) See Title 210 – Engineering, NEH Part 628, Chapter 52, Field Procedures Guide for the Headcut Erodibility Index, for a field guide and terminology used in the determination of the parameters that form the headcut erodibility index (K_h).

G. Mass Wasting

(1) Evaluate landslides and landslide potential at dam and reservoir sites, especially those involving shale formations, clay stratigraphy, and those where unfavorable dip-slope or other adverse rock attitudes occur.
(2) Summarize the history of mass movement in the project area. Carefully evaluate the static and seismic stability of dam abutments, auxiliary spillway cuts, and the reservoir rim. If sudden movements are possible, evaluate the effect of the potential landslide on displacement of reservoir water and resulting wave effects.

H. Subsidence

Consult the State geological survey and other data sources to investigate the potential for surface subsidence due to past or future solid, liquid (including groundwater), or gaseous mineral extraction.

I. Multipurpose and Water Retention Dams

Investigate and evaluate the groundwater regime and hydraulic characteristics of the entire reservoir area of water storage for potential leakage. Develop and analyze water budgets to assure the adequacy of the site to accomplish the intent of the project.

J. Other

Special studies and evaluations may be necessary where conditions such as the following occur at a site:

(i) Highly fractured bedrock (such as basalt or rhyolites)
(ii) Compacted shales
(iii) Some types of siliceous, calcareous, or pyritic shales
(iv) Expansive soils
(v) Soluble salts
(vi) Vertic soils
(vii) Mirabilite
(viii) Rebound or stress relief fractures (that may cause open fissures)
(ix) Sharp elevation changes in foundation materials
(x) Artesian waters.

631.0211 References

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