CHAPTER V

GEOTECHNICAL INVESTIGATIONS AND STUDIES

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GEOTECHNICAL INVESTIGATIONS AND STUDIES
(Dams, Dam Sites or Appurtenant Structures)

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Chapter V

GEOTECHNICAL INVESTIGATIONS AND STUDIES
(Dams, Dam Sites, or Appurtenant Structures)

5-1 GENERAL

An adequate assessment of site geologic and geotechnical conditions is one of the most important aspects of a dam safety evaluation. Evaluation of the safety of either a new or an existing dam requires, among other things, that its foundation has been adequately examined, explored, and investigated so that it is as fully understood as possible. Foundation explorations should be directed towards obtaining only such information as may be important to an evaluation of the dam. The exploration program should identify the factors that critically affect the safe performance of the dam, and not develop extraneous information. The following sections of this chapter briefly identify the principal methods commonly employed in foundation investigations, and are intended to suggest approaches and scopes of investigations which, when properly implemented, should comply with FERC requirements and expectations. It is emphasized that, because of the almost infinite variety of geologic conditions from site to site, it would be unreasonable and impractical to attempt to set forth in these Guidelines specific investigation programs.

While this chapter is principally directed toward dams and dam sites, the types of investigations and studies discussed are also applicable to other water retention structures and appurtenant structures of hydropower projects.

5-2 PURPOSE AND SCOPE

The purpose of this chapter is to present guidelines for use by FERC staff for determining the appropriateness and level of geotechnical investigations and studies for dams, water retention structures and other appurtenances. Reports on such investigations and studies must be included in the technical exhibits supporting; (a) applications for license, (b) final design reports, and (c) Part 12 reports (FERC Regulations, 18 C.F.R. Part 12) by independent consultants, when such reports have not been previously submitted or referenced.

The scope of this chapter is intended to outline the desirable quantity and quality of those investigations required to support design or evaluation conclusions. It is fully recognized that the specific investigation programs and studies for individual projects cannot realistically be standardized, and will vary widely according to site conditions, type of dam, hazard classification, and design phase.

5-3 REFERENCES

Selection of field investigation procedures, and use of data evaluation procedures supporting geologic or geotechnical reports, are acknowledged to be best guided by criteria and procedures available in qualified literature, as well as by proven local practice. Reliable sources include publications and manuals authored by the U.S. Corps of Engineers, U.S. Bureau of Reclamation, American Society of Civil Engineers, U.S. Committee on Large Dams, and other widely recognized engineering organizations. In each particular case, variations based on good judgment and experience are encouraged and differing approaches of scope and detail between government and private practice are realistically inevitable. Selected references are listed in Section 5-13

5-4 SOURCES OF PRE-EXISTING DATA AND INFORMATION

The geotechnical information and data presented in a licensee's or applicant's design report and in Independent Consultant's (Part 12) report, should incorporate references, where applicable to available FERC reports. The following reports may be useful:

- Operation Inspection Reports
- Construction Inspection Reports
- Independent Consultants' Safety Inspection Reports
- Other Inspection and/or Special Reports on existing dams or sites that are available

One or more of the above listed reports can be expected to be available for licensed projects. If a license has not previously been issued, the FERC staff engineer performing the review may have available the Prelicense Inspection Report prepared by the responsible FERC regional office.

For existing dams, geologic and geotechnical data may be available from the facility owner, previous owners, state or local agencies if the facility is a publicly owned project, and from the state agency responsible for dam safety. Also, geological information may be available from Corps of Engineers Phase I Inspection Reports of public or private entities having impounding structures upstream or downstream of the facility.

For proposed dams, the source of geotechnical information will generally be the licensee and/or the applicant's consultants and engineers.

For all proposed dams, the applicant will be required to provide those data necessary to evaluate whether the foundation of the proposed structure is adequate to safely construct the structure proposed for that site.

Data to be made available should include, where applicable:

- Logs of borings, test pits, and exploratory trenches
- Site geologic maps and reports
- Site seismicity reports
- Site geophysical reports
- Materials exploration and testing reports
- Reservoir rim conditions
- Reports and papers published by Geological Societies and Departments in their Bulletins
- Correspondence that may highlight geological changes or problems in the foundation
- Design drawings and specifications for foundation excavation and support
- Local landslide history
- Inspection records
- Maintenance records
- Aerial photography
- Seepage history
- Licensee's reports
- Construction photographs
- Concrete materials and mix design
- As built drawings
- Instrumentation and monitoring data

5-5 NEED FOR SUPPLEMENTAL INFORMATION

The preferred approach for assessing the adequacy of dam foundations should be to minimize the use of general assumptions as to foundation conditions and strength parameters. The objective of reviewing existing data is self-evident. Site-specific information and data-based analyses should be the prevalent basis for judgments on dam safety. If potentially hazardous foundation conditions are believed or determined to exist, and the existing data are insufficient to resolve the problem, it will be necessary to conduct supplemental investigations and analyses, or develop additional information to complete the evaluation. Appendix V-C provides step-by-step procedures for developing the parameters needed in a stability analysis. The supplemental information will usually involve additional explorations and testing, materials testing and seismic information.

Typical conditions that would require additional foundation explorations for existing dams are suggested below:

- Significant cracking, settlement or sloughing of dams or related nearby structures.

- Increase in settlement rates or indications of downstream movement.

- Uncontrolled seepage conditions under, through, and around foundations or abutments, and at the toe area of any water retention structures.

- Sudden or steady increase in observed seepage.

- Credible foundation data is insufficient to support stability analysis.

- Unexplained high or rapid rise in piezometric pressures either in the foundation or abutment material or within an embankment structure.

- Highly fractured, jointed rock.

- Rock formations that are known to be susceptible to seepage problems, solution activity or erodible material.

- Rock formations that are conducive to weak seams or planes with low strength characteristics and adverse orientation (i.e. downstream dip).

- Use of assumed high shear-strength parameters in a stability analysis that are not justified or supported.

- Request by an owner to allow use of a reduced fact
or of safety from the criteria normally required in Table 2 of Chapter 3.

5-6 GEOLOGICAL INVESTIGATION AND REVIEW

Geological Investigations should be conducted for new projects and reviewed for existing structures to determine the following:

- The general geologic setting of the area at and near the project.

- The geologic conditions related to selection of the site.

- The characteristics of the foundation soils and rocks.
- Any other geologic conditions that may influence design, construction, and long term operation.

- Seismicity of the area.

- The sources of construction material.

The extent of the investigations will depend on whether the project is proposed or existing and/or the design and the complexity of the local geology. The methods used for the investigations are dependent on the data that needs to be obtained to fully understand the foundation for both constructed and proposed projects. These investigative methods also depend on the types and size of the structures involved, and on the extent and quality of the information needed.

5-7 INTENSITY OF INVESTIGATIONS

The extent of required investigations should be dictated by hazard classification, nature of structures, and quantity of data already available. Existing dams without adequate data should be evaluated as carefully as proposed structures; not to do so is to be dangerously presumptive.

Geotechnical investigations for proposed sites should be generally divided into three separate phases to minimize costs and for developing the necessary data at each stage of the approval, design, and construction of a project:

- Preliminary Investigations (Adequate information to justify site selection and preliminary cost estimates).

- Initial Design Investigations (Information necessary to obtain regulatory approvals, refine cost estimates, and develop engineering and environmental data).

- Final Design Investigations (Information necessary for developing plans and specifications, obtaining bids, and constructing the project).

For existing dams, the extent of data needed may be relatively limited, depending upon the adequacy of existing data and construction documentation. Evaluation of an existing structure generally requires detailed foundation data that may only be obtained by drilling, sampling, and testing that is concentrated on specific site areas or problems. Such investigations, when needed, should be planned to provide the engineer with information and data to answer questions on specific dam safety problems and to perform dam safety analyses.

5-7.1 Preliminary Investigations (Adequate information to justify site selection and preliminary cost estimates).

This investigation should provide a first general impression of the engineering and geological aspects of the proposed site, and should determine if further study of the site is warranted. The field work generally would include preliminary field geologic mapping, some preliminary hand auger holes for soil and overburden sampling, a limited number of core holes into rock and possibly some preliminary seismic refraction lines. This information would be used to answer questions raised by an office study. The data would also be used to plan the type, location, and amount of explorations and laboratory testing required for future, more detailed investigations.

5-7.2 Initial Design Investigations (Information necessary to obtain regulatory approvals, refine cost estimates, and develop engineering and environmental data).

These investigations would be undertaken to provide more detailed information on foundation characteristics on a particular site or several sites, and to provide data for preliminary considerations of the design requirements and construction methods. This type of information is usually developed for inclusion in the license application or in reports providing conceptual analyses of existing project structures. This phase of field investigation should include surface and subsurface exploration and sampling through borings, test pits, test trenches, material testing, geologic mapping, and additional geophysical surveys to supplement drilling. Data developed from these activities should be used to compare alternative sites, to analyze different types of structures that might serve the same purpose, and to develop economic evaluations of the sites. An end product of this investigation usually is an application for license, which includes a specifically identified site and appurtenant structures.

5-7.3 Final Design Investigations (Information necessary for developing plans and specifications, obtaining bids and constructing projects).

These investigations would be primarily composed of detailed drilling, sampling, and testing concentrated on specific features at the selected project site; and should be specifically planned to provide the engineer with information that is necessary to design structures, estimate quantities, determine rates of construction progress, develop cost estimates, prepare plans and specifications, and obtain bids.

5-8 METHODS OF INVESTIGATIONS

The adequacy of the analysis of an engineered structure will normally be primarily dependent on the extent of the information known about foundation conditions of the site and the physical properties of the foundation materials. To evaluate these properties, the type and application of sampling methods is important. There is no single sampling method or sampling device that will guarantee the recovery of satisfactory samples in all materials, but the less disturbance to the sample, the more accurate the results will be from testing that sample. Different devices and techniques have been developed for drilling and sampling a wide variety of material types. Proper sampling is a combination of science and art. Although many procedures have been standardized, the alteration and adaptation of techniques are often dictated by specific investigation requirements.

5-8.1 Constructed Projects

For constructed projects, including evaluation of structures under Part 12 of the Commission's Regulations, the methods of investigation generally consist of researching available information as described in paragraph 5-4. However, if questions of project safety cannot be properly addressed by the use of existing data, then additional site specific field investigations should be required. This work will generally include explorations of the foundation, abutments, and structures themselves, using equipment and methods discussed in paragraph 5-8.2 below.

5-8.2 Unconstructed Projects

5-8.2.1 Types of Exploration

The general types of explorations used to investigate potential project sites fall into four categories (1) geologic reconnaissance and mapping (2) borings, (3) special excavations, and (4) geophysical measurements. These types of exploration methods are discussed in U.S. Corps of Engineers EM 1110-1-1804, and EM 1110-2-1907 (See References, Paragraph 5-13), and briefly presented in Appendix V-A.

5-8.2.1.1 Geologic Reconnaissance and Mapping

Geologic reconnaissance and mapping is crucial for understanding critical items influencing siting, design, and construction. It gives the overall picture. The geologic map is frequently the only "as built" drawing of the foundation conditions and is very useful in evaluating any stability, settlement or seepage problems that may occur during the operation of the project.

5-8.2.1.2 Borings

Of the different types of explorations, borings are the most practical and accurate method of obtaining sub-surface information. The most important aspect of the drilling procedures is the recovery of the material penetrated. A boring with low recovery is of limited value, and will generally raise more questions than it answers. (See Appendix V-A).

5-8.2.1.3 Special Excavations

Special excavations are defined as those openings made with machinery other than drill rigs for the purpose of obtaining soil or rock samples, or conducting insitu testing. They consist of test pits, test trenches, large diameter borings, tunnels, shafts, drifts or adits. (See Appendix V-A).

5-8.2.1.4 Geophysical

Geophysical explorations are an indirect method of obtaining generalized sub-surface geologic information by using special instruments to make certain physical measurements. Geophysical observations in themselves are not geologic facts, but are statistical and orderly measurements. Geophysical explorations complement core drilling, test pits, or other direct methods of sub-surface exploration and can provide a rapid evaluation of certain geologic conditions. However, their reliability is only as good as their confirmation by conventional means of exploration. (See Appendix V-A).

5-8.2.2 Location of Explorations

Adequate information about foundation properties and characteristics is critical to a full understanding of the adequacy of any design or in the evaluation of an existing structure. Therefore explorations should be adequately distributed over the dam site, including abutments and dam foundation, and in special cases at appurtenant structures, including penstocks, tunnels, spillways, intakes and outlets, at the powerhouse site, (whether surface or subsurface) along the reservoir rim, and at the material borrow sites.

5-8.2.3 Laboratory Tests

Laboratory testing of foundation material may include the performance of such routine tests as direct shear, unconfined and triaxial compression, sliding friction, modulus of elasticity, tensile strength, natural and dry density, moisture content, consolidation, Atterberg limits, grain-size analysis, and permeability. Less frequently, and where unusual geological conditions exist, tests for foundation rebound, slaking, collapsibility, dispersive characteristics, permeability, compaction, and determination of the mineral and chemical composition of the rock and ground water may be required. In addition, where liquefaction potential may need to be evaluated, dynamic laboratory tests such as cyclic direct shear and/or cyclic triaxial compression tests may be appropriate. (See References, Paragraph 5-13).

Laboratory tests may be needed to provide information regarding the behavior of foundation rock under the various construction conditions to which it will be subjected, such as, rebound due to removal of load, application of load, scour, exposure to weather, wet-dry, and freeze-thaw cycles. Laboratory tests are also necessary to establish the quality of construction materials such as concrete aggregate, impervious material, rockfill, and riprap. The interpretation, evaluation and application of the test results to the design of the structures is a highly important phase and depends to a great degree upon experience and judgment in correlating and weighing the data accumulated in the test program.

5-8.2.4 Field Tests

Two of the most important field tests performed are permeability and grouting. Permeability tests can be done either by pumping out or hydraulic pressure. These tests are discussed in the U.S. Army Corps of Engineers EM 1110-2-3506. (See References, Paragraph 5-13), and briefly presented in Appendix V-B.

The pumping-out test consists of bailing or pumping water from wells or boreholes and observing the effect of this operation on the water level in these and nearby holes. The test usually is performed in one or more of the exploratory borings.

The hydraulic pressure test consists of pumping water under pressure into an isolated zone in the rock or overburden through a borehole and noting the quantity of water pumped at any given pressure. Descriptions of pressure testing equipment and procedures are contained in EM 1110-2-3506.

Test grouting may be useful. It consists of performing experimental grouting operations on exploratory boreholes to determine, during the design stage, the extent to which subsurface materials are groutable.

While the above field tests may be used to provide information on the foundation, additional field (in-situ) tests for evaluating the physical characteristics of the rock mass as a whole may be justified as follows: Test blasting, rock bolt pull-out tests (RTH 323-80, Reference 16), flat jacking tests (RTH 365-80 & References 11,15 & 16), Goodman jacking tests (Reference 18), chamber tests, and direct shear strength (RTH 321-80, Reference 16).

5-9 INSTRUMENTATION AND MONITORING

5-9.1 General

Instrumentation is used to document preconstruction site conditions, to monitor the performance of a structure both during and after construction, and to provide evidence that design criteria are satisfied. In addition, analysis of seepage, leakage, pressure and movement data furnishes valuable background information for use in future design work. The extent of instrumentation for monitoring potential deficiencies at existing dams should take into account the hazard potential of a dam, or threat to life and property should there be a failure or sudden release of water from the project. Instrumentation should always be installed because it is a necessary supplement for monitoring the performance and long-term structural integrity of all significant and high hazard potential projects. If visual distress in the structure cannot be adequately monitored by existing instrumentation, additional supplemental instrumentation properly located and installed, should be provided to ensure proper monitoring. Some level of instrumentation may be useful on a case-by-case basis for low hazard potential projects. The extent of internal distress in a dam cannot always be directly measured. However, diagnostic procedures are available to assist in identifying problems. Table 5-1 can be used as an aid to assessing the causes of deficient behavior, and the means of detecting such problems. A key factor relevant to these procedures is effective instrumentation. A prudently located array of instrumentation specifically tailored to the given dam might include some of the following: Piezometers, observation wells, strain gages, extensometers, accelerographs, seismographs, inclinometers, tiltmeters, and alignment monuments (survey networks). The basic layout should be installed early so that monitoring can start during construction and continue after the project becomes operational. A comparison of operating conditions with design assumptions will help to determine whether the structure is performing satisfactorily. In selecting equipment, specific requirements are ruggedness, reliability over a long period, and simplicity of construction, installation, observation, and evaluation.

TABLE 5-1 Causes of Deficient Behavior, Means of Detection

Causes of Deficient Behavior	Means of Detection Measurement and Observations											
	Direct Observations	Relative Movements	Vertical Displacements	Angular Displacements	Horizontal Displacements	Uplift and Pore Pressure	Seismic Measurements	Rainfall Measurements	Flows	Turbidity	Sound Investigations	Crack and Joint Measurements
Concrete and Masonry Dams												
Due to foundation	X	X	X	X	X	X		X	X	X	X	X
Due to concrete	X		X	X	X			X	X		X	X
Due to unforeseen action[a]	X		X	X	X	X	X					
Due to structural behavior of arch and multiple arch dams	X		X	X	X						X	X
Due to structural behavior of gravity and buttress dams[b]	X		X	X	X						X	X
Due to maintenance[b]	X								X	X		
Earth and Rockfill Dams												
Due to foundation	X	X	X	X	X	X		X	X	X	X	
Due to embankment materials[c]				X		X						
Due to unforeseen actions[a]	X			X		X	X					
Due to structural behavior[d]	X	X	X	X	X	X		X	X	X	X	X
Due to maintenance[b]	X								X	X	X	
Reservoirs												
Slope sliding	X		X	X	X			X			X	
Movement of rock blocks	X		X	X	X						X	
Permeability	X					X			X	X		

[a] Or actions of exceptional magnitude, such as uplift, earthquakes, external or internal temperature variation, moisture variation, freezing and thawing.

[b] Includes periodic inspections, cleaning of drains, control of seepage, deterioration of instrumentation, maintenance of slope protection, burrowing animals.

[c] Includes method of construction: excludes filters and drains.

[d] Includes filters and drains.

SOURCE: ICOLD 1981

Since there are many types of dams and many different site conditions, each dam will have its own instrumentation needs that are specific to the type of structure. Some types of instruments are recommended for most dams, while others are recommended only in special cases. The number of instruments and frequency of observations should be carefully optimized. There should be reasonable balance between the level of surveillance sought and economy. Otherwise, the project could be burdened by unnecessary accumulations of data that may interfere with sensible problem analysis. As a minimum, alignment monuments should be installed at all existing high hazard potential dams.

5-9.2 Geotechnical Instrumentation

Table 5-2 below provides an inventory of frequently used geotechnical instruments and the usual factors measured and monitored. The following list of reference material covers details for installation of instrumentation basic to monitoring dams:

- U. S. Army Corps of Engineers Manual EM 1100-2-1908, Part 1 of 2, 31 Aug 71: Instrumentation of Earth and Rockfill Dams (Groundwater and Pore Pressure Observations); Chapter 5, Installation, Maintenance of Piezometers and Observations.

- U. S. Army Corps of Engineers Manual, EM 1110-2-1908, Part 2 of 2, 19 November 76: Instrumentation of Earth and Rockfill Dams (Earth Movement and Pressure Measuring Devices); Chapter 2, Movement Devices for Embankments and Foundations.

- U. S. Army Corps of Engineers Manual, EM 1110-2-4300, 15 September 80: Instrumentation of Concrete Structures, Chapter 3, Uplift and Leakage, and Chapter 4, Plumbing Instruments and Tilt Measuring Devices.

- The National Research Council Book, 1983: Safety of Existing Dams, Evaluation and Improvement, Chapter 10 Instrumentation.

- United States Bureau of Reclamation Manual, Embankment Instrumentation.

Adding instrumentation to existing dams often requires specialized equipment and drilling techniques for boreholes. During the drilling of boreholes, samples of materials and logs should be obtained of the borings. These data may be of significant value for subsequent data evaluation and predictions concerning the ongoing safety of the structure under operating conditions. The drilling, sampling and installation methods, and procedures must be specified and carefully monitored to prevent damage from these activities to the structure and the foundation.

Table 5-2 Inventory of Geotechnical Instruments	
Instrument	Phenomena Measured
Piezometer, closed & open systems, observation wells	Pore water and ground water measurements
Weirs, flow meters and flumes	Seepage measurements
Temperature sensors	Temperature measurements of groundwater, seepage and indirectly rock
Extensometer, inclinometers	Internal deformation measurement
Tiltmeters	Rotational and tilting measurement of embankment and rock concrete dams and their foundations
Survey equipment	Deformation measurements horizontal and vertical
Crack Monitor	Crack movement measurements

5-10 SPECIAL GEOLOGIC HAZARD STUDIES

Special geological hazard studies may be required for a project that is to be located in an area likely to be subject to active natural geologic forces, such as volcanic and seismic activity. Evaluation of geologic hazards is extremely important in determining if a site is safe for the construction of a project. Therefore, it is important that the owner of a project demonstrate that the site is geologically suitable and that natural geologic conditions have been considered and evaluated in the project design.

5-10.1 Volcanic Hazards

Potential hazards from volcanoes are significant in the western states and Alaska. The U.S. Geological Survey has published a map showing volcanic hazards in the United States (Mullineaux 1975); this map shows no hazard east of New Mexico.

Volcanic hazards can be separated into two categories on the basis of distance from the volcano. For sites close to volcanoes, there is a high potential hazard for hydro projects to be affected by debris flows or mudflows, ash falls and lava flows. In addition, volcanic activity may also result in earthquakes which may cause severe ground shaking. For projects distant from volcanoes, the most significant hazard may be ash falls resulting from major explosions. Secondary effects may include volcanically induced seiches and floods caused either by the melting of ice on the volcanic cone (Mt. St. Helens) or failure of dams in valleys draining the slopes of the volcano. Debris or mud flows into nearby full reservoirs could cause extensive flooding and endanger the structure.

5-10.2 Seismic Hazards

Many regions of the world are subject to potentially destructive earthquakes. The west coast of the United States is best known for seismic activity. However there are other significant seismic areas in the Central, Midwest, Northeast and Southeast sectors. In highly seismic regions, where earthquakes occur frequently and are actively studied, the seismic hazard is better understood. In regions of low seismic frequency and/or intensity, where destructive quakes occur infrequently, the actual danger to structures may be much greater because the seismic hazard is often not well understood or is not given the attention it deserves. Therefore, it is imperative that more than just a cursory evaluation be given to data to be used in performing stability analysis for a project. The occurrence of an earthquake in the vicinity of a dam can cause damage or even failure if earthquake loadings have not been given adequate consideration during the design phase.

The study to define the seismic hazard at a proposed project site should include the following:

- **Seismological investigations.** Studies are made of the past occurrence of earthquakes in the general region of the site, and on that basis estimates are made of the probability of future earthquakes. In order for this approach to be valid, a sufficiently long seismic history must be available.

- **Geological investigations.** In this investigation an evaluation is made of the tectonic processes in the general site region. Faults in the general region are identified and the degree of activity of the faults is estimated.

- **Site soils and geology investigations.** Investigations are made of geological formations, soil deposits and rock at the site area to assess their possible behavior during earthquake shaking, and how they might affect the ability of a structure to resist earthquakes.

- **Liquefaction Investigations.** Where liquefaction potential may need to be evaluated, field
and laboratory tests may be appropriate. These tests can be an aid to determining the cyclic stress levels which may cause liquefaction of a soil.

Judgment based on the information provided by the above investigations must then be used to establish appropriate earthquake design criteria for the project. This study should be detailed in the project geotechnical report.

5-11 SUBMITTAL OF GEOTECHNICAL REPORT

The geotechnical investigative data, including results of laboratory and field tests, should be submitted in the Geotechnical Report which is part of the supporting design report for new projects. The Geotechnical Report is required because the design of all structures depends on the strengths and weaknesses of the material they are founded on or in. In the independent consultants' reports for existing dams, and particularly for those that have a long, satisfactory service record, such data as may be available should be presented in the summary of geological conditions pursuant to Part 12 of the Commission's Regulations. All geotechnical reports should consist of a succinct presentation of those geological conditions that contribute to characterization of the project site and determination of the design of the various structures.

The Geotechnical Report required for new projects should present a comprehensive assessment and description of the geology of the project. It should be limited, however, to an effective combination of brief discussions, tabulated data, and geological illustrations to depict the conditions that are of engineering significance. The information in the reports should focus on the following topics:

1. Significant and controlling topographic conditions.

2. Description of all aspects of bedrock and recent geology, including discussions of: (a) composition and structure of the rock, (b) engineering description of soils and of their relationship to the bedrock, (c) principal engineering properties of the rocks and soils as determined by field and laboratory investigations, (d) geologic conditions that present special engineering problems, (e) remedies proposed or used for the special problems, and (f) sources and characteristics of construction materials.

The surface and subsurface investigations, laboratory tests, and geological illustrations in geotechnical reports should be sufficiently comprehensive to supply reliable information on all geological conditions that can influence the design, construction and cost of the project. Unless a separate seismological report is required, the geotechnical report should review the earthquake history of the region.

Following is a list of illustrative material that should be included in the geotechnical report, and, for the most part, included or referenced in the geological summary in an independent consultant's report.

- Project Location Map

- Reservoir-Geology map

- Plan of Explorations

- Logs of Exploratory Borings

- Laboratory Test Plots and Tabulations
- Site Geology Map
- Photographs
- Top of Rock Contour Map
- Geologic Structure Map
- Geologic Sections and Profiles

Geologic sections and profiles should show correlation of soil and rock units together with such significant features as water levels, water losses, faults, shear zones, foliations, jointing, and solution zones. The sections should also emphasize geologic structure and show depths of primary and secondary weathering. All sections and profiles should be superimposed with outlines of the principal structures and the depth of foundation excavation for existing or proposed structures.

Further, all geologic investigations and tests required for developing information on any of the following construction items should be completed and included in the report:

- Excavation slopes
- Special rock excavation methods for structural excavations.
- Rock bolting for slope stabilization or tunnel rock support.
- Foundation treatment by grouting or dental concrete filling.
- Protection of weather-sensitive foundations, such as shale, pending their burial.
- Special design and construction problems related to elastic rebound in foundation materials.

5-12 SUMMARY

In summary, it must be remembered that no matter how well a project's structures have been engineered, if the foundation conditions are not understood and taken into account, dam safety problems could occur. This chapter is not intended to be a detailed text on engineering geology, drilling techniques and program planning, sampling and laboratory testing procedures, or monitoring. It is intended as a guide for the reviewing engineer to determine if the quantity and quality of the investigations and studies performed support the design and/or conclusions presented. Section 5-13 provides a sampling of reference material for the above activities.

5-13 REFERENCES

1. U. S. Army Corps of Engineers, "Geotechnical Investigations," EM 1110-1-1804, Feb. 1984

2. U.S. Army Corps of Engineers, "Geophysical Exploration", EM 1110-1-1802, May 1979

3. U.S. Army Corps of Engineers, " Laboratory Soils Testing," EM 1110-2-1906, November 1970

4. U. S. Army Corps of Engineers, "Soil Sampling," EM 1110-2-1907, Mar 1972

5. U. S. Army Corps of Engineers, "Tunnels and Shifts in Rock," EM 1110-2-2901, Sept 1978

6. U. S. Army Corps of Engineers, "Grouting Technology," EM 1110-2-3506, Jan 1984

7. U. S. Army Corps of Engineers, "Instrumentation of Earth and Rockfill Dams," EM 1110-2-1908, Part 1 of 2, Aug 1976

8. U. S. Army Corps of Engineers, "Instrumentation of Earth And Rockfill Dams," EM 1110-2-1908, Part 2 of 2, Nov 1976

9. U. S. Army Corps of Engineers, "Instrumentation of Concrete Structures," EM 1110-2-4300, Sept 1980

10. U. S. Bureau of Reclamation, Dept. of the Interior, "Dams and Public Safety," a Water Resources Technical Publication, 1983

11. Wahlstron, Ernest E. "Tunneling in Rock," Elsevier Scientific Publishing Co. 1973

12. Alfred R. Golze, "Handbook of Dam Engineering," Van Norstrand Reinhold Company, 1977

13. National Research Council (U.S.) Committee on the Safety of Existing Dams," Safety of Existing Dams - Evaluation and Improvements," National Academy Press, 1983

14. Peck, Ralph; Hanson, Walter E.; Thornburn, Thomas H.; "Foundation Engineering," 2nd Edition, John Wiley & Sons, 1973

15. Goodman, Richard E., "Introduction to Rock Mechanics," John Wiley & Sons, 1980 (second edition)

16. U.S. Army Engineering Waterway Experiment Station, "Rock Testing Handbook," 1980 with updates

17. Electric Power Research Institute. "Guidelines for Drilling and Testing Core Samples at Concrete Gravity Dams," EPRI GS-6365, May 1989

18. ICOLD Bulletin 21 and 22: USCOLD "General Considerations Applicable to Performance Monitoring of Dams," December 1986

19. Sherard et Al "Earth and Earth Rock Dams: Engineering Problems of Design and Construction," John Wiley and Sons, 1963

5-14 APPENDICES

APPENDIX V-A

Types of Exploration

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Types of Exploration

Exploration is needed to refine the overall picture obtained from geologic mapping, for collecting samples to obtain specific design parameters, and to define specific features identified in geologic mapping that require specific attention as they relate to design and construction. The general types of field explorations used to investigate sites are:

Borings

Of the different types of explorations, borings are the most practical and accurate method of obtaining sub-surface information. Borings are divided into soil and rock types or a combination of both. The most important aspect of the drilling procedures is the recovery of the material penetrated. A boring with low recovery is of little value, and will generally raise more questions than it answers.

In soil borings the two prevalent methods for obtaining samples are the earth auger and the 2-inch split spoon drive sampler. For investigative sampling it is better to use a bucket auger as the continuous flight auger can provide misleading results in many situations by mixing the material as it moves up the flights. The 2-inch split spoon sampler is also used in performing the Standard Penetration Test (SPT). While the samples obtained by these two methods are considered disturbed, they provide the basis for determining if, where, and what types of "undisturbed" samples are needed. The primary method for obtaining undisturbed soil samples is by the Shelby tube sampler. See Reference No. 4, EM 1110-2-1907 (Soil Sampling) for detail on soil sampling.

For rock sampling, core borings are the most common method. Size of the rock core borings can range in diameter from 1 1/2 inches (EX) to 7 3/4 inches (6 x 7 3/4 inches), but the most common size used for exploratory work is 3 inches (NW). The NW size drilling usually produces good core recovery. Large diameter holes and special drilling equipment and methods may be justified in some types of rocks if better recovery and/or identification, sampling and testing of material are required, and in extracting the concrete/rock interface intact. The equipment and procedures for drilling and sampling are given in detail in reference No. 1. (Geotechnical Investigations), EM 1110-1-1804.

Equally important as obtaining as complete a sample as possible, with little disturbance, is the need to maintain the natural moisture content of the rock or soil sample. Material that may possibly be used for laboratory testing should be wrapped and/or waxed immediately upon removal from the sampler to preserve the natural moisture content.

Standard Sizes for Core Drills
Diamond Core Drill Manufacturers Assoication (DCDMA)

Designation	Core Size (in)	Hole Size (in)
EX/EW	0.845	1.485
AX/AW	1.185	1.890
BX/BW	1.655	2.360
NX/NW	2.155	2.980
AQ*	1.062	1.890
BQ*	1.432	2.360
NQ*	1.875	2.980
HQ*	2.500	3.782
PQ*	2.344	4.828
2-3/8 X 3-7/8**	2.375	3.875
4 X 5-1/2**	4.000	5.500
6 X 7-3/4**	6.000	7.750

* Wire line series
** Large diameter series

Special Excavations

Special excavations are defined as those openings made with machinery other than drill rigs for the purpose of obtaining soil or rock samples, or conducting in-situ testing. They consist of test pits, test trenches, large diameter borings, tunnels, shafts, drifts or adits. These excavations expose large areas of subsurface material thus permitting examination of in-situ subsurface conditions, recovery of large undisturbed samples, in-situ testing, installation of instrumentation, and evaluation of abnormalities. Some of these excavations require sheeting and shoring to protect the investigators as required by OSHA.

Test pits are openings excavated vertically from the ground surface to expose the sub-surface material for in-situ examination. Excavation is generally performed by backhoe, clam bucket or by hand. They are also used as a means of obtaining undisturbed samples of soil materials. Test pits are most often used in connection with soils exploration and testing. Test pits may also be used to study the character of the overburden-bedrock contact, and the position, characteristic, and condition of the bedrock surface and strata.

Test trenches are similar functionally to test pits, except that they are usually limited to relatively shallow depths and extend over a greater length. Excavation of trenches is usually done by bulldozer. Trenches are particularly useful for continuous exploration, examination and sampling of soils foundations; and for examining and correlating bedrock surface conditions that cannot be defined as accurately by conventional drilling and sampling methods. Combined with test pits, trenches are a more reliable method of determining the occurrence, composition, distribution, structure, and stability of unsatisfactory materials in deep alluvial and residual soil foundations for high dams.

Tunnels and drifts are nearly horizontal underground openings and passages which are excavated by standard mining methods. They vary in size and shape depending on the purpose and type of material being tunneled. The principal function of tunnels as an exploratory device is to permit detailed examination of the composition and geometry of rock structures such as joints, fractures, faults, shear zones, and solution channels where these conditions affect foundation stability, excavation, and treatment. Although a slower investigatory approach, excavation of exploration tunnels should be used when other methods do not supply adequate information. Geologic logging of the exploration tunnels should be done concurrently with the excavation when possible. Sampling and insitu rock testing may also be done during the excavation.

Geophysical

Geophysical explorations are an indirect method of obtaining generalized sub-surface geologic information by using special instruments to make certain physical measurements. Geophysical observations in themselves are not geologic facts, but are statistical and orderly measurements. The geologic information is obtained indirectly through analysis or interpretation of these measurements. The technology for such investigations has improved in recent years; therefore, geophysical testing has gained acceptance among design engineers and geologists as accuracy has improved. However, since these results are not subject to direct visual verification, geophysical exploration requires boreholes or other direct geological exploration for references and control of measurements. Geophysical explorations complement core drilling, test pits, or other direct methods of sub-surface exploration and can provide a rapid evaluation of certain geologic conditions. The cost of geophysical explorations is generally low compared with the cost of core borings or test pits, and considerable savings may often be affected by judicious use of this exploration method in conjunction with other methods.

APPENDIX V-B

Field Permeability and

Groutability Tests

APPENDIX V-B

Field Permeability and Groutability

Field tests to measure the permeability/groutability of the foundation material and the approximate yield of water are:

1. Pumping-Out Test

The pumping-out test consists of bailing or pumping water from wells or boreholes and observing the effect of this operation on the water level in these and nearby holes. The test usually is performed in one or more of the exploratory borings. Records are kept of the water levels before pumping, the time at which pumping is started, rate of pumping, amount of drawdown in the borehole, the time of each drawdown measurement, and the rate of water level rise after pumping has stopped.

2. Pumping-In Test (Hydraulic Pressure)

The hydraulic pressure test consists of pumping water under pressure into an isolated zone in rock or alluvium in a borehole and noting the quantity of water pumped at any given pressure. In general, water pressure should be limited to 1 pound per square inch per foot of depth in rock and to 0.5 pound per square inch per foot of depth of overburden to avoid damaging the foundation. The information obtained is used in appraising the leakage potential of the foundation, and in estimating grouting requirements for reducing seepage and controlling uplift pressures.

3. Field Grouting Test

Test grouting consists of performing experimental grouting operations on exploratory boreholes to determine, during the design stage, the extent to which subsurface materials are groutable. Grout is pumped into boreholes to full-depth or in sections isolated by packers. Detailed records are kept of the grouting operations. The results are evaluated on the basis of the consistencies and quantities of grout injected in relation to the pressures used, rate of injection, and time. Test grouting affords a method of estimating grout requirements, and in many instances gives more reliable data than pressure testing. Direct correlation between permeability and groutability has not been reliably established.

APPENDIX V-C

FERC Parameters for Developing Stability Analyses

APPENDIX V-C

FERC Parameters for Developing Stability Analysis

The necessary steps required to adequately address the parameters required in developing stability analyses are presented for constructed and unconstructed dams. Determining potential modes of failure is common to both.

Constructed Projects Shear Strength Parameters

Determine the need for additional field studies:

- Determine if condition of dam, as specified by Section 5-5, warrants supplemental foundation information.
- Perform preliminary stability analyses with the friction angle (N) parameter selected from the available records or from the literature and find the cohesion (c) values necessary to meet FERC safety factors for all loading conditions. Use effective uplift/pore pressure information if available, otherwise use full uplift pressure or total pore pressure, as mentioned in the Guidelines.
- Perform a sensitivity analysis for N using the most conservative value for c that resulted from the previous analysis. If the condition of the dam is acceptable and the most conservative c and N values are within a defensible range, no field investigations would be necessary.

Plan for investigations:

- Identify the potentially weak shear planes by using the existing information. If no information is available, use engineering judgement to define reasonable criteria for selecting such planes.
- Identify the types of tests and their scale (lab or field) as specified by section 5-8.2.1.
- Select the location of explorations as indicated by section 5-8.2.2.
- Prepare the specifications for the investigations.

Exploration and Testing

Dams on Bedrock Foundations

- Recover intact cores of concrete, bedrock and at the dam/foundation interface for classification and testing. It is recommended that three borings be taken as a minimum at the center or deep section of the dam and one at each abutment. For long structures, more borings may be advisable at 100 to 200 feet intervals. More borings should be taken as necessary to document any anticipated foundation problems (i.e. presence of clay seams).

- Drilling must be core type and the use of double or triple split barrels is highly recommended. The diameter of the samples should be no less than that obtained from NW size equipment. Preferably, for concrete the diameter should be approximately six inches depending on maximum size of aggregate.

- Core samples should be prepared for performing direct and triaxial shear tests on intact rock cores and cores containing potential weaker failure planes. These tests will provide approximate values of cohesion and angle of internal friction to be used in sliding stability analyses of the dam. Test results of intact samples will give upper bound shear strength values while tests on smooth surfaces give lower bound results.

- Unconfined compressive tests should be performed on intact rock samples to determine unconfined compressive strength of the bedrock. This data will be used to index rock characteristics and determine if the foundation has adequate bearing capacity to resist the loads imposed by the dam under all credible loading conditions.

Dams on Soil Foundations

- Recover a series of "undisturbed" soil samples from all zones of the embankment and the foundation, for index, classification and engineering property tests. It is recommended that test borings be generally located as above with the exception that all zones of material must be sampled.

- The types of index and classification tests for the soil will be selected based on the nature of the material. Cohesive soils should be tested for liquid and plastic limits. Clean sands and gravels are tested for gradation limits. Based on these tests, the need for further investigations for liquefaction potential should be assessed.

- Undisturbed soil samples should be tested for shear strength by either triaxial compression or direct shear apparatus. The tests should be based on the proposed loading conditions and drainage condition under which the dam will be subjected.

Constructed Projects Uplift Pressure Parameters

Determine the need for additional information

- If the preliminary analysis using full uplift and/or pore pressure indicated in section 5-13.1.1 will result in defensible shear strength parameters, no additional information will be necessary; otherwise:

- Perform a sensitivity analysis to find the range of a reduction in the uplift pressure that would warrant defensible shear strength parameters. If the uplift reduction would have results within an acceptable range, engineering judgement should be used to determine if the collection of additional information would be beneficial.

Plan for collecting additional information

- Locate the measurement sections as mentioned in section 5-8.2.2.

- Review the instrumentation discussion in section 5-9 and if so determined, install piezometers in the embankment at the interface and within the foundation bedrock or soil foundation to monitor pore pressures and define the phreatic surface in the embankments and to measure uplift pressures at the base of or below the dam at a possible foundation sliding plane. Readings should be taken over a period of several months, at periods of high flows if possible, to assess the functioning of internal drainage systems.

Unconstructed Projects Shear Strength Parameters

Field Studies

- Perform geological investigation as mentioned in section 5-6 to determine design criteria for the required investigations.

- Plan preliminary investigations (section 5-7.1), initial design investigations (section 5-7.2) and final design investigations (section 5-7.3) using the appropriate types of exploration (section 5-8.2.1), locations of exploration (section 5-8.2.2) and types of laboratory tests (section 5-8.2.3).

Proposed Dams on Bedrock Foundations

- Inspect and map the bedrock foundation noting joints or any other structural discontinuities that may require remedial measures.

- Recover a series of intact rock samples of the foundation to determine the orientation of bedding planes and for index and classification testing.

- Perform direct or triaxial shear tests on the intact core samples to determine appropriate design values for cohesion and angles of internal friction. This data will be used to assess the sliding stability of the dam along potential failure planes within the foundation rock below the dam.

- A series of unconfined compressive tests should also be made to determine the bearing capacity of the bedrock below the dam, occasionally the bearing capacity of the foundation bedrock will control the design of the proposed dam.

Proposed Dams on Soil Foundations

- If the situation requires more detailed analysis, a field reconnaissance to photograph and map all major foundation features should be done under the direction of an experienced geologist and/or geotechnical engineer.

- A series of borings should be taken to define the geologic stratigraphy and to obtain "undisturbed" samples for index and in-situ tests.

- If feasible, test pits or trenches should be excavated to determine in situ subsurface conditions and recover larger soil samples for testing.

- In-situ testing is performed to determine appropriate shear strength parameters. Available test procedures include the Standard Penetration Test, direct shear, field vane shear, dutch cone.

- In-situ testing to determine stress conditions is important to assess the effect on the foundation from construction of the proposed dam. Available test procedures include overcoring, flatjack and hydrofracture.

- An evaluation of deformation characteristics of the foundation and consolidation due to imposed loadings of the dam under all credible loading conditions should be made to determine the need for any special remedial measures.

Unconstructed Projects Uplift Pressure

Instrumentation and Monitoring

- Determine the type and location of the instrumentation (section 5-9.2).

- Design the monitoring program.

Reporting and Controls

- Perform Quality Assurance/Quality Control of the specified investigations and specified instrumentation.

- Prepare the Geotechnical Report (section 5-11), including the distribution of the foundation shear parameters.

- Summarize the monitoring program in the final Geotechnical Report.