RECLAMATION
Managing Water in the West

Design Standards No. 13

Embankment Dams

Chapter 12: Foundation and Earth Materials Investigation
Phase 4 (Final)

U.S. Department of Interior
Bureau of Reclamation

July 2012

Mission Statements

The U.S. Department of the Interior protects America's natural resources and heritage, honors our cultures and tribal communities, and supplies the energy to power our future.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

Design Standards Signature Sheet

Design Standards No. 13

Embankment Dams

DS-13(12)-7: Phase 4 (Final)
July 2012

Chapter 12: Foundation and Earth Materials Investigation

Foreword

Purpose

The Bureau of Reclamation (Reclamation) design standards present technical requirements and processes to enable design professionals to prepare design documents and reports necessary to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public. Compliance with these design standards assists in the development and improvement of Reclamation facilities in a way that protects the public's health, safety, and welfare; recognizes needs of all stakeholders; and achieves lasting value and functionality necessary for Reclamation facilities. Responsible designers accomplish this goal through compliance with these design standards and all other applicable technical codes, as well as incorporation of the stakeholders' vision and values, that are then reflected in the constructed facilities.

Application of Design Standards

Reclamation design activities, whether performed by Reclamation or by a non-Reclamation entity, must be performed in accordance with established Reclamation design criteria and standards, and approved national design standards, if applicable. Exceptions to this requirement shall be in accordance with provisions of *Reclamation Manual Policy*, Performing Design and Construction Activities, FAC P03.

In addition to these design standards, designers shall integrate sound engineering judgment, applicable national codes and design standards, site-specific technical considerations, and project-specific considerations to ensure suitable designs are produced that protect the public's investment and safety. Designers shall use the most current edition of national codes and design standards consistent with Reclamation design standards. Reclamation design standards may include exceptions to requirements of national codes and design standards.

Proposed Revisions

Reclamation designers should inform the Technical Service Center (TSC), via Reclamation's Design Standards Website notification procedure, of any recommended updates or changes to Reclamation design standards to meet current and/or improved design practices.

Chapter Signature Sheet
Bureau of Reclamation
Technical Service Center

Design Standards No. 13

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Chapter 12: Foundation and Earth Materials Investigation

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Chapter 12 – Foundation and Earth Materials Investigation is an existing chapter within Design Standard 13 and was revised to include:

- Updated chapter content to reflect modern investigations practice
- Added content and/or detail describing guidelines for photogrammetry, drilling and sampling in embankment dams, borehole optical televiewer imagery, Becker Penetration Tests, and care, retention, and disposal of drill core and samples
- Added figures, photographs, tables, and appendices
- Updated references

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Chapter 12

Foundation and Earth Materials Investigation

12.1 Introduction

12.1.1 Purpose

The purpose of conducting an investigation of foundation and earth materials is to obtain information about these materials for use in analysis, design, construction, and performance monitoring of a structure. The detail of the investigation should be commensurate with the magnitude and type of structure involved, the study being undertaken, and the stage of the project. On all dam projects, the watertightness of the foundations, the suitability of the foundations for the dam and appurtenant structures, and the construction material sources are important geological and engineering considerations.

12.1.2 Scope

This chapter of the Design Standards describes exploration and sampling procedures for investigations of new dams, existing dams, and borrow materials. Investigations of existing dams may be made for the purpose of dam safety evaluation or modification design and construction. Borrow investigations may be made of proposed construction materials in the vicinity of the dam or proposed dam.

Since a great amount of information specific to foundation and earth materials investigation is presented in detail in various publications, only a brief review of these topics is given here, and those publications are referenced. Reliable sources include publications and manuals authored by the Bureau of Reclamation (Reclamation), U.S. Army Corps of Engineers (USACE), American Society of Civil Engineers (ASCE), Natural Resources Conservation Service (NRCS), the American Society for Testing and Materials International (ASTM), and other widely recognized engineering organizations.

12.1.3 Applicability

This design standard is applicable to new dams and appurtenant structures to be constructed, existing structures under safety investigations, or structures that are to be modified because of changes in project purpose. Investigation of existing structures is very specific in nature and incorporates geologic and geotechnical data available at the time of design and construction. In situations where these data are not available, the purpose of the investigation should be to obtain the data necessary to make a reliable evaluation of the safety of the structure.

12.1.4 Deviations from Standard

Foundation and earth materials investigations for embankment dams and appurtenant structures should conform to this standard. Deviations from this standard should be documented and approved. The rationale for not using the standard should be described in the documentation. The technical documentation must be approved by appropriate line supervisors and managers.

12.1.5 Revisions of Standard

This chapter will be revised as its use dictates. Comments or suggested revisions should be forwarded to the Chief, Geotechnical Services Division (86-68300), Bureau of Reclamation, Denver, Colorado 80225; they will be comprehensively reviewed and incorporated as needed.

12.2 Field Investigations

Information relating to foundation conditions and to natural materials available for construction is essential in the design of new dams and evaluation and modification of existing dams. The investigations are conducted in the field and in the laboratory, with analyses and reference research performed in the office. For efficiency, the search for data must be properly planned.

12.2.1 Planning

The early stage of the investigation should include reviewing geologic data of the area, such as geologic maps, aerial photographs, and all types of geologic reports; descriptions of existing quarries and borrow areas; their production records; and materials performance histories. Many governmental agencies (including local, State, and Federal) maintain records of the quantity of each type of construction material produced and frequently include an estimate of the reserves at each quarry.

When planning a drilling program at an existing structure, first consider if the need for the activity justifies the potential risk to the structure created by the planned program. As is standard procedure with Reclamation's Dam Safety Program and general procedure, a determination of potential consequences if no action is taken should be made to compare with subsequent investigation cost estimates and prioritization of Reclamation programs. These consequences should include current risk, as well as the likelihood that conditions will worsen or that drilling will create a problem, which could drive up future cost of remediation if required. If possible, determine the consequences with available data. However, a scaled down investigation program, preferably with no drilling, may be required before an adequate assessment can be performed.

If the solution is investigative and data collection is justified, a multidiscipline exploration team should be assembled to determine exploration components required to adequately address the data needs. The exploration team should consist of the principal and/or geotechnical engineer, the principal geologist, geophysicists, and experts in laboratory analysis, in situ testing, or other disciplines as needed. The exploration team should thoroughly discuss data needs and investigation plans to ensure compatibility.

A thorough search of all available records should precede any investigation program. Reclamation sources of information that could be useful in evaluating the need to collect additional data include:

- Personnel who have previously worked on the dam
- Geologic mapping, logs, and reports from previous investigations and construction
- Safety of Dams data books
- Comprehensive Facility Review/Comprehensive Review reports
- Geotechnical Services Division files
- Earth materials reports (retained by the Materials Engineering and Research Laboratory)
- Technical records of design and construction
- Instrumentation reports or data
- Archived records
- Construction (L-29) reports
- Project records in regional office and at the project site.

The exploration program should consider:

- The need for the program
- Purpose of the investigation
- Potential dam failure modes
- Past performance of the structure
- Cost of the exploration

- Acceptable drilling and investigative methods
- Equipment availability
- Required sample type and size (disturbed or undisturbed)
- Depth, diameter, and inclination of drilling required
- Materials to be drilled and sampled
- Access for equipment
- Utilities, surface and underground obstacles, and accessibility
- Conduits, structures, and instrumentation in the dam
- Dam embankment and foundation geometry and hazard of fracturing
- Instrumentation and completion requirements

The investigation will likely require clearances, permits, and traffic control plans. The investigation schedule must allow time to obtain clearances and permits. In most cases, National Environmental Policy Act compliance activities will be required. Under the National Historic Preservation Act, some sites may require inspection by an archeologist and a permit from the State Historic Preservation Officer. Reclamation's regional or area offices can assist with these activities.

No dam should be drilled or investigated without review of the Emergency Action Plan (EAP). Reclamation dams have EAPs in place; copies may be obtained from the governing regional or area office, or from the Instrumentation and Inspections Group of the Technical Service Center. The EAP lists the key individuals who should be contacted and informed of proposed activities. There are documented case histories where drilling has caused incidents with dams, and knowledge of the EAP and good communications were key contributors to safely solving the problems. In some cases for construction, interim EAP supplements have been developed and should also be consulted.

As with all Reclamation field activities, a specific job hazard analysis should be prepared prior to commencing work.

12.2.2 General Considerations for Specific Site Investigations

Site investigations are seldom a simple procedure requiring only conscientious adherence to a set of hard and fast rules. Unless the team is guided by mature judgment and has relevant practical experience in this field, much time and money may be wasted. A thorough knowledge of geology, rock, and unconsolidated masses is of tremendous value because factual knowledge is limited to soil and rock conditions along vertical lines (explorations, outcrops) spaced far apart, and interpretation of geologic conditions between these locations is required. The results of interpolation can be misleading unless the investigators have a fairly clear conception of the soil and rock profile under investigation. Knowledge of the geology is also helpful in determining the stress history at the site. The results of site investigations are ultimately condensed into a set of assumptions that constitute the basis for design [1, 2].

Subsurface investigations can be costly and should only be considered after the exploration team performs initial records review and site reconnaissance. The team should list the design and analysis issues and data requirements. After considering the engineering properties needed and the required costs of the investigations, the team should select the proper investigation method. The team should consider the importance of the required data and decide the level of investigations required to satisfy design data or analytical requirements.

Investigations should be based on engineering and a conceptual geologic model that have been developed prior to conducting an exploration program. The primary goal of an exploration program is then to verify the engineering and geologic assumptions previously conceived by the design team.

12.2.3 Protection of the Environment

Once locations for field investigations have been determined, routes of access to the areas and to the specific sites for borings and excavations should be selected with care to minimize damage to the environment. This is usually the responsibility of the regional members of the exploration team.

The type and operation of equipment to perform the investigation must be controlled at all times, and the extent of damaged areas will be held to the minimum consistent with the requirements for obtaining adequate data. Advance all subsurface explorations so as to prevent ground water pollution or impact to the ground water regime. Discharge, drill fluid, and sealing of individual aquifers are governed by Federal, State, and local requirements. After the exploratory sites have served their purpose, the disturbed areas will be restored to their original state and have a natural appearance to the degree possible within practical considerations [3].

Federal, State, and local laws that relate to environmental protection are to be followed during investigations. Final selection of material sources may be strongly influenced by the ability to conform economically to the restraints imposed by these regulations and the acceptability of environmental impacts.

The team should observe relevant features in the area, including:

- Utility locations
- Access issues
- Conditions of nearby structures
- Geologic constraints
- Surface conditions
- Private property boundaries
- Potential borrow sources

12.2.4 Field Reconnaissance

Site reconnaissance proceeds after the necessary precursory information is obtained. A team consisting of a geologist, geotechnical engineer, and design engineer should perform the reconnaissance, and the site should be viewed completely. The team should also inspect the surrounding area. For example, the stability of surrounding highway and railroad cut slopes should be inspected. Existing structures can be examined. The team should visit with authorities familiar with geology and construction in the area to determine any unknown or unforeseen problems. During the inspection, alternate site alignments or structure locations should be evaluated.

Investigations for dam foundations and construction materials are usually concerned with two questions: (1) What construction materials are available in the area? (2) What quantity and quality of each construction material are available within a reasonable haul distance? In considering construction of a dam, proper selection of the design of the dam to be built at a site is greatly influenced by the construction materials available.

Other good sources of information include a vehicular inspection of the area to observe road cuts and existing excavations of all kinds. Interviews with local contractors, residents, geologists, soil scientists, and geotechnical drilling firms in the area often reveal where undeveloped or little used construction materials exist. In addition, they can provide precautionary information about conditions that might affect investigations.

In instances where foundations of dam sites have been investigated by others, data obtained from borings, trenches, or other geologic explorations should be used. Even though these sites may be some distance away from the proposed sites, if foundation conditions are anticipated to be similar, valuable information may be gained that may reduce the amount of exploration requirements, thus reducing the time and cost of the exploration.

Reclamation's Materials Engineering and Research Laboratory maintains a complete library of earth, rock, and concrete materials testing reports for existing Reclamation projects that are being investigated. They also maintain a database of thousands of aggregate and riprap sources available in the western U.S., which can be accessed to find nearby quarries.

12.2.5   Field Exploration Request

Reclamation assembles an exploration team that develops a formal "Field Exploration Request" (FER) to conduct explorations specific to project requirements and construction requirements [3] [37]. The exploration team identifies and discusses specific data requirements and methods to obtain the data. The exploration team is a multidisciplinary team that can include representatives from geotechnical and/or civil engineering, engineering geology, geophysical, laboratory (materials testing specialist), drill foreman, construction liaison specialist, and regional/area offices. Other disciplines (such as environmental compliance, surveys) are included based on need.

The FER is the best estimation by the team of the work required. The FER should be flexible if methods are not working or revealed site conditions dictate changes. In addition, FERs are normally phased to allow for review of data adequacy. Communication between design and field staff throughout the exploration process saves both time and effort. A clear understanding of the issues being investigated allows the field personnel to adapt to potentially different geologic conditions than expected [1, 2].

FERs may include subsurface exploration, surface mapping, topographic information, miscellaneous survey requirements, laboratory testing planned, hole completion details, instrumentation, records search, maps and locations of explorations depicted, sample transportation, geophysical testing, etc. Considerations may be included for electronic transfer of information. Appendix A is an example of a FER.

12.3   Surface Exploration

A relationship between topographic features or landforms and the characteristics of subsurface soils has been shown repeatedly. Thus, the ability to recognize terrain features on maps, on aerial photographs, and during field reconnaissance, combined with an understanding of geological processes, can be of great assistance in locating sources of construction materials, in making a general appraisal of foundation conditions, and in locating explorations. The processes that develop soil deposits are associated with water, ice, wind, and gravity action for transported soils, and the mechanical-chemical action of weathering for residual soils. For transported soils, each process tends to produce typical landforms. Soils associated with similar landforms usually have similar physical properties. The persons responsible for foundation and construction programs for dams should become familiar with landforms and soils associated with them.

In the investigation of foundations or materials, the principal purposes of the explorations are to define stratigraphy, to secure representative samples of the soil or rock either for visual examination or for laboratory testing, or to perform in situ tests. To a large degree, samples from explorations and their subsequent testing determine foundation conditions and locations and properties of construction materials for dams. Erroneous conclusions could be drawn if the samples or tests are not truly representative of site conditions. Considerable care is required in obtaining samples because of the variations in natural deposits of earth materials.

The sizes of samples depend on the nature of the laboratory tests that may be required. For information on required sizes of samples, and directions for care and shipping of samples, refer to the *Earth Manual* [1, 9].

12.4 Geologic Field Mapping

Considerable useful engineering information is obtainable from geologic maps and cross sections, which identify the soil and rock units and major geologic structures directly underlying the reservoir, structure sites, and surrounding area. Refer to *Design of Small Dams*, chapter 5 [38], and reference [7]. It is advisable to prepare preliminary geologic maps and geologic sections before making subsurface borings to provide an indication of the geologic conditions and anticipated design considerations at a site. Maps and sections will permit borings to be strategically located and can be particularly important in economically formulating and conducting a comprehensive foundation investigation. The process of progressively refining the model of the geologic structure and stratigraphy by correlating surface with subsurface data is the most efficient and cost-effective way to develop an understanding of geologic site conditions. For existing dams and reservoirs, seepage locations should be accurately mapped and quantities estimated. Refer to the *Final Design Process* [8].

12.4.1 Mapping of Vicinity

The purpose of vicinity mapping is to develop an accurate picture of the geologic and physiographic setting of the project. The area and degree of detail to be mapped can vary widely, depending on the type and size of the project and on regional geology. In general, the area to be mapped should include the project site(s), as well as the surrounding area that could influence the project or be influenced by the project. Only when existing geologic studies of an area have been combined with current geologic mapping and appropriate satellite imagery can a vicinity mapping program be considered complete [3, 4, 5, 6]. The mapping should include existing and new geologic mapping.

12.4.2 Site Mapping

Small-scale and detailed geologic maps should be prepared for specific sites of interest within the project area and should include proposed structure and reservoir areas, as well as borrow and quarry sites. Development of the geology of surficial deposits and bedrock materials is essential during site mapping and subsequent explorations. Determination of subsurface features should be derived from a coordinated, cooperative study by geotechnical engineers, geologists, and geophysicists and should be portrayed two or three dimensionally with cross sections.

12.4.3 Aerial Photography and Satellite Imagery

An aerial photograph may be a vertical photograph in which the axis of the camera is vertical, or nearly so, or an oblique photograph in which the axis of the camera is inclined. Low-angle oblique photographs include the horizon, while high-angle oblique photographs do not. Vertical, stereoscopic photographs are commonly used as the basis for topographic mapping, agricultural soil mapping, and geological interpretations. Identification of features shown on the photographs is facilitated by stereoscopic examination. The features are then interpreted for a particular purpose such as geology, land utilization, or engineering. The entire area of the United States has been covered by aerial photography and satellite imagery. Although cameras have also been carried on spacecraft such as the Space Shuttle, satellites more frequently use electronic scanners to record ground scenes in digital form. These sensors record reflected or emitted energy in the visible, near-infrared, and thermal-infrared portions of the spectrum. Although certain satellite images are distributed as photographic film or prints, they are more often distributed as digital products. Index maps of the United States are available through the U.S. Geological Survey in Washington, DC, and the U.S. Department of Agriculture (USDA). These maps show which Government agency provides data for a particular area.

Interpretation of earth materials and geologic features from aerial photographs is extremely useful but requires much experience and field checking. The diagnostic features include terrain position, topography, drainage and erosional features, areas of outcrops, lineations, color tones, and vegetative cover. Interpretation is limited mainly to surface and near-surface conditions [4, 5].

Aerial photographs can be used to identify certain terrain types and landforms. Stereoscopic photograph inspection of an area, taking particular note of regional topography, local terrain features, and drainage conditions, will usually suffice to identify the common terrain types. This permits the possible range in soil and rock materials to be anticipated and their characteristics to be defined within broad limits. This work is best accomplished by field office personnel who are familiar with the area.

Geologic features that may be highly significant to the location or performance of engineering structures sometimes can be identified from aerial photographs. In many instances, these features can be more readily identified on the aerial photographs than on the ground. Joint sets, landslides, fault zones, folds, and other structural features sometimes are identified quickly in an aerial photograph, whereas it may be difficult to find these structures on the ground.

Other important things that can be identified from aerial photographs are erosional features and color tones. Erosional features have significance in that they often reflect textural characteristics of the exposed material. Color tones, including photographic gray values and black and white, have a general significance in that they reflect soil moisture conditions and often reveal the relative position of the ground water table. Light color tones are usually associated with well-drained soils, such as gravels and sands, with ground water levels well below the ground surface. Vegetative cover is significant in that the patterns produced in aerial photographs often reflect the nature of soil and moisture conditions. Near-infrared color imagery is particularly sensitive to healthy plant foliage. The color infrared aerial photographs collected for the National Agricultural Imagery Program (NAIP) by the USDA provide a means for monitoring plant growth associated with dam seepage. NAIP images are collected on a 1- to 5-year basis for the entire country and are available via USDA Internet geographic information servers.

Also, a change in vegetative pattern may indicate a change in the engineering characteristics of the underlying bedrock. Use of vegetation as an indication of material types on aerial photographs requires field correlation. For detailed information and descriptions of geologic field mapping, see references [1, 4, 5].

12.4.4 Photogrammetry

Photogrammetry is a three-dimensional measuring technique that uses overlapping photographs taken in a manner that mimics the perspective centers of human stereoscopic vision. The photogrammetric process determines a three-dimensional location from two-dimensional images of a scene. Close range photogrammetry, also known as terrestrial photogrammetry, uses images obtained from as close as inches to as far away as a mile or so. Images can be obtained from land, a boat, a mast, a lift basket, a helium balloon, and while hanging from ropes.

Photogrammetric products include:

- Digital Terrain Model
- Elevation contours
- Volume measurements
- Geologic discontinuity measurements
- Orthophotographs – scaled and world oriented (if survey data is obtained)
- Scaled three-dimensional models

Advantages of photogrammetry include rapid data acquisition, high quality data (hundreds of thousands of points), and low cost (camera and lens cost less than $300).

Limitations of photogrammetry include obstructions such as vegetation, equipment that creates errors or gaps in data set, and shadows that can produce undesirable results.

12.5 Geophysical Exploration

Geophysical explorations consist of making measurements from the earth's surface or in boreholes to obtain subsurface information. Additional explorations are needed for reference, control, and verifying geophysical interpretations. Surface geophysical explorations may be of greatest value when performed early in the field exploration program in combination with limited subsurface explorations. Surface geophysical explorations are appropriate for rapid location and correlation of geologic features such as stratigraphy, lithology, discontinuities, and ground water; and borehole geophysics are used for in situ measurement of elastic moduli and densities. Geophysical explorations, especially shear wave velocity, provide valuable information in earthquake studies of existing dams [1, 4, 5, 6].

The major surface geophysical exploration methods are seismic, electrical resistivity, sonic, electromagnetic, radar, self-potential, magnetic, and gravity. The major subsurface borehole geophysical and wireline survey methods are electric logging, nuclear radiation, acoustic/seismic, caliper, directional, fluid temperature, gravity, magnetic, and borehole flowmeter. Table 12.5-1 summarizes the application, advantages, and limitations of selected geophysical methods.

Table 12.5-1. The Application, Advantages, and Limitations of Selected Geophysical Methods

Method	Principle and application	Limitations
Surface seismic refraction	Determine bedrock depths and characteristic wave velocities as measured by geophones spaced at intervals.	May be unreliable unless velocities increase with depth and bedrock surface is regular. Data are indirect and represent averages. Limited to depths of about 30 m (100 ft).
High resolution reflection	Determine depths, geometry, and faulting in deep rock strata. Good for depths of a few thousand meters. Useful for mapping offsets in bedrock. Useful for locating ground water.	Reflected impulses are weak and easily obscured by the direct surface and shallow refraction impulses. Does not provide compression velocities. Computation of depths to stratum changes requires velocity data obtained by other means.
Vibration	Travel time of transverse or shear waves generated by a mechanical vibrator is recorded by seismic detectors. Useful for determining dynamic modulus of subgrade reaction for design of foundations of vibrating structures.	Velocity of wave travel and natural period of vibration gives some indication of soil type. Data are indirect. Usefulness is limited to relatively shallow foundations.
Uphole, downhole, and cross-hole surveys (seismic direct method)	Obtain velocities for particular strata; dynamic properties and rock-mass quality. Energy source in borehole or at surface; geophones on surface or in borehole.	Unreliable for irregular strata or soft soils with large gravel content. Cross-hole measurements best suited for in-place modulus determination.
Electrical resistivity surveys	Locate fresh/salt water boundaries; clean granular and clay strata; rock depth; depth to ground water. Based on difference in electrical resistivity of strata.	Difficult to interpret and subject to wide variations. Difficult to interpret strata below water table. Does not provide engineering properties. Used up to depths of about 30 m (100 ft).
Electromagnetic conductivity surveys	Measures low frequency magnetic fields induced into the earth. Used for mineral exploration; locating near surface pipes, cables, and drums and contaminant plumes.	Fixed coil spacings limited to shallow depth. Background noise from natural and constructed sources (manufactured) affects values obtained.
Magnetic measurements	Mineral prospecting and locating large igneous masses. Highly sensitive proton magnetometer measures Earth's magnetic field at closely spaced intervals along a traverse.	Difficult to interpret quantitatively, but indicates the outline of faults, bedrock, buried utilities, or metallic objects in landfills.
Gravity measurements	Detect major subsurface structures, faults, domes, intrusions, cavities. Based on differences in density of subsurface materials.	Not suitable for shallow depth determination but useful in regional studies. Some application in locating caverns in limestone.
Ground-penetrating radar	Locate pipe or other buried objects, bedrock, boulders, near surface cavities, extent of piping caused by sink hole and leakage in dams. Useful for high-resolution mapping of near-surface geology.	Does not provide depths or engineering properties. Shallow penetration. Silts, clays, and salts, saline water, the water table, or other conductive materials severely restrict penetration of radar pulses.

Table 12.5-1. The Application, Advantages, and Limitations of Selected Geophysical Methods (continued)

Method	Principle and application	Limitations
Electrical logging	Several different methods available. Provides continuous record of resistivity from which material types can be deduced when correlated with test-boring data.	Provides qualitative information. Best used with test-boring information. Limited to uncased hole.
Neutron radiation logging	Provides continuous measure of natural moisture content. Can be used with density probe to locate failure zones or water bearing zones in slopes.	Data from neutron probe is limited to in-place moisture content values. Often differs from oven-dried moisture content and requires correction.
Gamma-gamma logging	Provides continuous measure of in-place density of materials.	Data limited to density measurements. Wet density usually more accurate than dry density.
Scintillometer (Gamma ray logging)	Provides measure of gamma rays. Used to locate shale and clay beds and in mineral prospecting.	Qualitative assessments of shale or clay formations.
Acoustic borehole imaging	Sonic energy generated and propagated in fluid such as air to water. Provides continuous 360° image of borehole wall showing fractures and other discontinuities. Can be used to determine dip.	Must be used in fluid-filled borehole unless casing is being inspected. Tool must be centered in the borehole. Logging speed is relatively low between 20 and 75 mm/s (4 and 15 ft/min). Images less clear than those obtained with borehole cameras.
Acoustic velocity logging	Can determine lithologic contacts, geologic structure, cavities, and attitude of discontinuities. Elastic properties of rock can be calculated. Compression (P-water) is generated and measured. Used almost exclusively in rock.	Borehole must be fluid filled and diameter accurately known. Penetration beyond borehole wall of about a meter or so. Geologic materials must have P-water velocities higher than velocity of the borehole fluid.
Crosshole seismic tests	Seismic source in one borehole; receiver(s) at same depth in second (or more) borehole(s). Material properties can be determined from generated and measured compression and shear waves. Low velocity zones underlying high velocity zones can be detected.	Borehole spacing is critical and should be >3 m and <15 m. Precise borehole spacing must be accurately known for data to be useful.
Borehole cameras	Borehole TV or film type cameras available. TV viewed in real time. Can examine cavities, discontinuities, joints, faults, water well screens, concrete-rock contacts, grouting effectiveness, and many other situations.	Requires open hole. Images are affected by water clarity. Aperture on film camera must be preset to match reflectivity of borehole wall materials.
Borehole caliper logging	Used to continuously measure and record borehole diameter. Identify zones of borehole enlargement. Can evaluate borehole for positioning packers for other tests. One to six arm probe designs.	Diameter ranges from about 50 to 900 mm (2 to 36 in). Must calibrate caliper against known minimum and maximum diameter before logging. Special purpose acoustic caliper designed for large or cavernous holes (dia.) 1.8 to 30 m (6 to 100 ft).
Temperature logging	Continuous measure of borehole fluid temperature after fluid has stabilized. Can determine temperature gradient with depth.	Probe must be calibrated against a fluid of known temperature. Open boreholes take longer to stabilize than cased holes. Logging speed 15 to 20 mm/s (3 to 4 ft/min).

12.6 Soil Classification

Most soils are a heterogeneous accumulation of mineral grains that are not lithified. However, the term "soil" or "earth," as used by engineers, includes virtually every type of uncemented or partially cemented inorganic and organic material found in the ground. Only hard rock, which remains firm after exposure, is wholly excluded. To the engineer engaged in design and construction of foundations and earthworks for dams, the physical properties of soils, such as unit weight, permeability, shear strength, compressibility, and interaction with water, are of primary importance.

It is advantageous to have a standard method of identifying soils and classifying them into categories or groups which have distinct engineering properties. This enables engineers in the design office and in the field to speak the same language. Knowledge of soil classification, including typical engineering properties of soil of the various groups, is especially valuable to the person engaged in prospecting for earth materials or investigating foundations for structures.

In 1952, Reclamation and the USACE, with Professor Arthur Casagrande of Harvard University as a consultant, reached agreement on a modification of Professor Casagrande's airfield classification, which was named the Unified Soils Classification System (USCS). This system, which is particularly applicable to the design and construction of dams, takes into account the engineering properties of soils, is descriptive and easy to associate with actual soils, and has the flexibility of being adaptable both to the field and to the laboratory.

Reclamation last standardized their USCS system requirements in 1986, as documented in the *Soil Classification Handbook* [39]. These procedures are also documented in the *Engineering Geology Field Manual* [4] and *Earth Manual* [9]. The adopted procedures require detailed word descriptions when classifying soils. Any further reference in this design standard to soil classification of borrow or foundation materials should comply with these requirements.

12.6.1 Classification Method

Particles larger than 3 inches are not considered when assigning classifications according to the USCS. The amount of oversize material, however, may be of great importance in the selection of sources for embankment material; hence, logs of explorations should always contain information on quantity and size of particles larger than 3 inches.

Within the particle size range of the USCS, there are two major divisions: coarse-grained particles and fine-grained particles. Coarse-grained particles are those larger than the No. 200 sieve (0.075 millimeter [mm]), and they are further divided as follows:

Gravel (G), from 3 inches (75 mm) to No. 4 sieve (about 0.25 inch [6 mm]):
- Coarse gravel - 3 inches to 0.75 inch (19 mm)
- Fine gravel - 0.75 inch to No. 4 sieve

Sand (S), from No. 4 sieve to No. 200 sieve:
- Coarse sand - No. 4 to No. 10 sieve
- Medium sand - No. 10 to No. 40 sieve
- Fine sand - No. 40 to No. 200 sieve

Fine-grained particles (fines) are smaller than the No. 200 sieve, and there are two types of fines: silt and clay. Whether a soil is a silt or clay is based on plasticity characteristics, not on particle size. In other publications, the distinction between clay and silt is made based on the amount of fines greater than or less than a 2-micron or 5-micron sieve size in the hydrometer test.

The percentage of gravel, sand, and fines in a soil determines whether a soil is coarse grained or fine grained. A fine-grained soil contains 50 percent or more fines, while a coarse-grained soil contains less than 50 percent fines.

Organic material is often a component of soil, but it has no specific grain size. It is distinguished by the composition of its particles rather than by their sizes, which range from colloidal-sized particles of molecular dimensions to fibrous pieces of partly decomposed vegetable matter several inches in length.

Soils in nature seldom exist separately as gravel, sand, silt, clay, or organic matter but are usually found as mixtures with varying proportions of these components. The USCS is based on recognition of the type and predominance of the constituents, considering grain size, gradation, plasticity, permeability, and compressibility. In the field, identification is accomplished by visual examination and by a few simple hand tests for fine-grained soils or the fine-grained fraction. In the laboratory, specific index property tests are performed to verify the field classification and more accurately identify the soil. Both field and laboratory tests need to be performed to the extent that the surficial deposits are well understood.

Table 12.6.1-1 summarizes the USCS system for soils [2]. Table 12.6.1-2 illustrates how the USCS can be used to select soils for different engineering purposes [1].

Table 12.6.1-1. USCS Soil Classification Chart – Laboratory Method

Criteria for assigning group symbols and group names using laboratory tests [1]				Soil classification: Group symbol	Soil classification: Group name [2]
Coarse-grained soils More than 50% retained on No. 200 sieve	**Gravels** More than 50% of coarse fraction retained on No. 4 sieve	**Clean gravels** Less than 5% fines [3]	Cu ▾ 4 and 1 ▾ Cc ▾ 3 [5]	GW	Well-graded gravel[6]
			Cu < 4 and/or 1 > Cc > 3 [5]	GP	Poorly graded gravel[6]
		Gravels with fines More than 12% fines [3]	Fines classify as ML or MH	GM	Silty gravel[6,7,8]
			Fines classify as CL or CH	GC	Clayey gravel[6,7,8]
	Sands 50% or more of coarse fraction passes No. 4 sieve	**Clean sands** Less than 5% fines [4]	Cu ▾ 6 and 1 ▾ Cc ▾ 3 [5]	SW	Well-graded sand
			Cu < 6 and/or 1 > Cc > 3 [5]	SP	Poorly graded sand[9]
		Sands with fines More than 12% fines [4]	Fines classify as ML or MH	SM	Silty Sand [7,8,9]
			Fines classify as CL or CH	SC	Clayey sand [7,8,9]
Fine-grained soils 50% or more passes the No. 200 sieve	**Silts and clays** Liquid limit less than 50	inorganic	PI > 7 and plots on or above "A" line [10]	CL	Lean clay [11,12,13]
			PI < 4 or plots below "A" line [10]	ML	Silt [11,12,13]
		organic	$\frac{\text{Liquid limit-oven dried}}{\text{Liquid limit-not dried}}$? 0.75	OL	Organic clay [11,12,13,14] Organic silt [11,12,13,15]
	Silts and clays Liquid limit 50 or more	inorganic	PI plots on or above "A" line	CH	Fat clay
			PI plots below "A" line	MH	Elastic silt [11,12,13]
		organic	$\frac{\text{Liquid limit-oven dried}}{\text{Liquid limit-not dried}}$? 0.75	OH	Organic clay [11,12,14,15] Organic silt [11,12,14,16]
Highly organic soils		Primarily organic matter, dark in color, and organic odor		PT	Peat

[1] Based on the material passing the 3-in (75-mm) sieve.
[2] If field sample contained cobbles and/or boulders, add "with cobbles and/or boulders" to group name.
[3] Gravels with 5 to 12% fines require dual symbols
- GW-GM well-graded gravel with silt
- GW-GC well-graded gravel with clay
- GP-GM poorly graded gravel with silt
- GP-GC poorly graded gravel with clay

[4] Sands with 5 to 12% fines require dual symbols
- SW-SM well-graded sand with silt
- SW-SC well-graded sand with clay
- SP-SM poorly graded sand with silt
- SP-SC poorly graded sand with clay

[5] Cu = D60/D10 $C_c = \frac{?D_{30}?^2}{D_{10} \times D_{60}}$

[6] If soil contains ▾ 15% sand, add "with sand" to group name.
[7] If fines classify as CL-ML, use dual symbol GC-GM, SC-SM.
[8] If fines are organic, add "with organic fines" to group name.
[9] If soil contains ▾ 15% gravel, add "with gravel" to group name.
[10] If the liquid limit and plasticity index plot in hatched area on plasticity chart, soil is a CL-ML, silty clay.
[11] If soil contains 15 to 29% plus No. 200, add "with sand" or "with gravel" whichever is predominant.
[12] If soil contains ▾ 30% plus No. 200, predominantly sand, add "sandy" to group name.
[13] If soil contains ▾ 30% plus No. 200, predominantly gravel, add "gravelly" to group name.
[14] PI ▾ 4 and plots on or above "A" line.
[15] PI < 4 or plots below "A" line.
[16] PI plots on or above "A" line.
[17] PI plots below "A" line.

Table 12.6.1-2. Engineering Use Chart for Compacted Soils

Engineering Properties of Compacted Soil[1]						Relative Desirability for Various Uses (No. 1 is considered the best)							
						Rolled earth dams			Canal sections		Foundations and fills		
Soil group name	Group symbol	Perme-ability[2]	Shear strength (saturated)	Compressibility (saturated)	Workability as a construction material	Homo-geneous embank-ment	Core	Shell	Erosion-resistant blanket or belt	Compacted earth lining	Imper-vious	Per-vious	Resistance to frost heave
Well-graded gravel	GW	Pervious	Excellent	Negligible	Excellent	—	—	1	1	—	—	1	1
Poorly graded gravel	GP	Pervious	Good	Negligible	Good	—	—	2	2	—	—	3	2
Silty gravel	GM	Semipervious to impervious	Good	Negligible	Good	2	4	—	4	4	1	4	6
Clayey gravel	GC	Impervious	Good to fair	Very low	Good	1	1	—	3	1	2	6	5
Well-graded sands	SW	Pervious	Excellent	Negligible	Excellent	—	—	3 if gravelly	6	—	—	2	3
Poorly graded sands	SP	Pervious	Good	Very low	Fair	—	—	4 if gravelly	7 if gravelly	—	—	5	4
Silty sands	SM	Semipervious to impervious	Good	Low	Fair	4	5	—	8 if gravelly	5 erosion critical	3	7	12
Clayey sands	SC	Impervious	Good to fair	Low to medium	Good	3	2	—	5	2	4	8	7
Silt	ML	Semipervious to impervious	Fair	Medium	Fair	6	6	—	—	6 erosion critical	6	9	11
Lean clay	CL	Impervious	Fair	Medium	Good to fair	5	3	—	9	3	5	10	9
Organic silt and organic clay	OL	Semipervious to impervious	Poor	Medium to high	Fair	8	8	—	—	—	7	11	—
Elastic silt	MH	Semipervious to impervious	Fair to poor	High	Poor	9	9	—	—	—	8	12	10
Fat clay	CH	Impervious	Poor	High	Poor	7	7	—	10	—	9	13	8
Organic silt and organic clay	OH	Impervious	Poor	High	Poor	10	10	—	—	—	10	14	—
Peat and other highly organic soils	PT	—	—	—	—	—	—	—	—	—	—	—	—

[1] Compacted to at least 95 percent of laboratory maximum dry density or to at least 70 percent relative density.
[2] Impervious: < 1 ft/yr (1 x 10^{-6} cm/s)
Semipervious: 1 to 100 ft/yr (1 x 10^{-6} cm/s to 1 x 10^{-4} cm/s).
Pervious: > 100 ft/yr (1 x 10^{-4} cm/s).

12.6.2 Soil Deposits

When investigating soil deposits for borrow materials or embankment dam foundations, it is important to develop an understanding of the geologic age, geologic processes, and forces of nature that contributed to formation of the soil deposits. There are numerous weathering, erosional, and depositional processes that form soils, and a detailed study and explanation of these processes are beyond the scope of this document. Geologic textbooks provide the most detailed information on the formation of soil deposits, and Reclamation's *Earth Manual* also provides good general information on landform types as related to soil deposits. It is important to understand that certain types of soil deposits can be problematic in the engineering design of embankment dam foundations. Understanding how soils were formed can help with investigating and developing material borrow areas.

The processes that develop soil deposits are water, ice, wind, and gravity action for transported soils, and mechanical-chemical processes for residual soil. A soil deposit may be the product of several of these mechanisms.

Table 12.6.2-1 is a summary of soil deposits and their properties. A detailed description of the various landforms, how they were formed, and the types of material they contain can be found in the Earth Manual [1].

Table 12.6.2-1. Principal Soil Deposits and Their Properties

Major Division	Principal Soil Deposits	Pertinent Engineering Characteristics
SEDIMENTARY SOILS -		
Residual		
Material formed by disintegration of underlying parent rock or partially indurated material.	Residual sands and fragments of gravel size formed by solution and leaching of cementing material, leaving the more resistant particles; commonly quartz.	Generally favorable foundation conditions.
	Residual clays formed by decomposition of silicate rocks, disintegration of shales, and solution of carbonates in limestone. With few exceptions becomes more compact, rockier, and less weathered with increasing depth. At intermediate stage may reflect composition, structure, and stratification of parent rock.	Variable properties requiring detailed investigation. Deposits present favorable foundation conditions except in humid and tropical climates, where depth and rate of weathering are very great.
Organic		
Accumulation of highly organic material formed in place by the growth and subsequent decay of plant life.	Peat. A somewhat fibrous aggregate of decayed and decaying vegetation matter having a dark color and odor of decay.	Very compressible. Entirely unsuitable for supporting building foundations.
	Muck. Peat deposits which have advanced in stage of decomposition to such extent that the botanical character is no longer evident.	

Table 12.6.2-1. Principal Soil Deposits and Their Properties (continued)

Major Division	Principal Soil Deposits	Pertinent Engineering Characteristics
TRANSPORTED SOILS – Alluvial Material transported and deposited by running water.	Floodplain deposits. Deposits laid down by a stream within that portion of its valley subject to inundation by floodwaters.	
	Point bar. Alternating deposits of arcuate ridges and swales (lows) formed on the inside or convex bank of mitigating river bends. Ridge deposits consist primarily of silt and sand, swales are clay-filled.	Generally favorable foundation conditions; however, detailed investigations are necessary to locate discontinuities. Flow slides may be a problem along riverbanks. Soils are quite pervious.
	Channel fill. Deposits laid down in abandoned meander loops isolated when rivers shorten their courses. Composed primarily of clay; however, silty and sandy soils are found at the upstream and downstream ends.	Fine-grained soils are usually compressible. Portions may be very heterogeneous. Silty soils generally present favorable foundation conditions.
	Backswamp. The prolonged accumulation of floodwater sediments in flood basins bordering a river. Materials are generally clays but tend to become more silty near riverbank.	Relatively uniform in a horizontal direction. Clays are usually subjected to seasonal volume changes.
	Alluvial Terrace deposits. Relatively narrow, flat-surfaced, river-flanking remnants of floodplain deposits formed by entrenchment of rivers and associated processes.	Usually drained, oxidized. Generally favorable foundation conditions.

Table 12.6.2-1. Principal Soil Deposits and Their Properties (continued)

Major Division	Principal Soil Deposits	Pertinent Engineering Characteristics
(cont'd) Materials transported and deposited by running water.	Estuarine deposits. Mixed deposits of marine and alluvial origin laid down in widened channels at mouths of rivers and influenced by tide of body of water into which they are deposited.	Generally fine-grained and compressible. Many local variations in soil conditions.
	Alluvial-Lacustrine deposits. Material deposited within lakes (other than those associated with glaciation) by waves, currents, and organo-chemical processes. Deposits consist of unstratified organic clay or clay in central portions of the lake and typically grade to stratified silts and sands in peripheral zones.	Usually very uniform in horizontal direction. Fine-grained soils generally compressible.
	Deltaic deposits. Deposits formed at the mouths of rivers which result in extension of the shoreline.	Generally fine-grained and compressible. Many local variations in soil condition.
	Piedmont deposits. Alluvial deposits at foot of hills or mountains. Extensive plains or alluvial fans.	Generally favorable foundation conditions.
Aeolian		
Material transported and deposited by wind.	Loess. A calcareous, unstratified deposit of silts or sandy or clayey silt traversed by a network of tubes formed by root fibers now decayed.	Relatively uniform deposits characterized by ability to stand in vertical cuts. Collapsible structure. Deep weathering or saturation can modify characteristics.
	Dune sands. Mounds, ridges, and hills of uniform fine sand characteristically exhibiting rounded grains.	Very uniform grain size; may exist in relatively loose condition.

Table 12.6.2-1. Principal Soil Deposits and Their Properties (continued)

Major Division	Principal Soil Deposits	Pertinent Engineering Characteristics
Glacial		
Material transported and deposited by glaciers, or by melt-water from the glacier.	Glacial till. An accumulation of debris, deposited beneath, at the side (lateral moraines), or at the lower limit of a glacier (terminal moraine). Material lowered to ground surface in an irregular sheet by a melting glacier is known as a ground moraine.	Consists of material of all sizes in various proportions from boulders and gravel to clay. Deposits are unstratified. Generally present favorable foundation conditions; but, rapid changes in conditions are common.
	Glacio-Fluvial deposits. Coarse and fine-grained material deposited by streams of meltwater from glaciers. Material deposited on ground surface beyond terminal of glacier is known as an outwash plain. Gravel ridges known as kames and eskers.	Many local variations. Generally present favorable foundation conditions.
	Glacio-Lacustrine deposits. Material deposited within lakes by meltwater from glaciers. Consisting of clay in central portions of lake and alternate layers of silty clay or silt and clay (varved clay) in peripheral zones.	Very uniform in a horizontal direction.
Marine		
Material transported and deposited by ocean waves and currents in shore and offshore areas.	Shore deposits. Deposits of sands and/or gravels formed by the transporting, destructive, and sorting action of waves on the shoreline.	Relatively uniform and of moderate to high density.
	Marine clays. Organic and inorganic deposits of fine-grained material.	Generally very uniform in composition. Compressible and usually very sensitive to remolding.

Table 12.6-2.1. Principal Soil Deposits and Their Properties (continued)

Major Division	Principal Soil Deposits	Pertinent Engineering Characteristics
Colluvial		
Material transported and deposited by gravity.	Talus. Deposits created by gradual accumulation of unsorted rock fragments and debris at base of cliffs.	Previous movement indicates possible future difficulties. Generally unstable foundation conditions.
	Hillwash. Fine colluvium consisting of clayey sand, sand silt, or clay.	
	Landslide deposits. Considerable masses of soil or rock that have slipped down, more or less as units, from their former position on steep slopes.	
Pyroclastic		
Material ejected from volcanoes and transported by gravity, wind and air.	Ejecta. Loose deposits of volcanic ash, lapilli, bombs, etc.	Typically shardlike particles of silt size with larger volcanic debris. Weathering and redeposition produce highly plastic, compressible clay. Unusual and difficult foundation conditions.
	Pumice. Frequently associated with lava flows and mud flows, or may be mixed with nonvolcanic sediments.	

12.7 Rock Classification

Rock as an engineering material is defined as lithified or indurated crystalline or noncrystalline materials. Rock is encountered in masses and as large fragments, which have consequences to design and construction differing from those of soil. Based on the principal mode of origin, rocks are grouped into three broad categories: igneous, sedimentary, and metamorphic [4].

12.7.1 Classification Method

There are numerous systems in use for field and petrographic classification of rocks. Many classifications require detailed petrographic laboratory tests and microscopic examination of thin sections, while others require field tests and limited petrographic examination. Reclamation established a classification system which is modified from R.B. Travis [7]. While not based entirely on field tests or field identification of minerals, many of the classification categories are sufficiently broad to make field identification possible. Even where differences in the mineral constituents cannot be determined precisely in the field, they usually are not significant enough to affect the engineering properties of the rock if classified somewhat incorrectly by lithologic name. Detailed mineralogical identification and petrographic classification can be performed on hand samples or core samples submitted to the Technical Service Center's Petrographic Laboratory.

The *Engineering Geology Field Manual* contains a thorough discussion of rock and its related subjects [4].

Uniformity of definitions, descriptions, and identification of rock is important to maintain continuity in geologic logs, drawings, and reports from a project with multiple drilling sessions, different loggers, and mappers, and to accurately convey rock descriptions to the designer.

Also important is the recording of all significant observable parameters when describing rock properties. Engineering geology rock descriptions should include:

- Rock unit (member or formation) name
- Lithology with lithologic descriptors
- Bedding/foliation/flow texture
- Weathering
- Hardness/strength
- Contacts
- Discontinuities (includes fracture indexes)
- Permeability data (as available from testing)
- Moisture conditions

A simple rock properties classification table (table 12.7.1-1) is included below [42].

Table 12.7.1-1. Intact Rock Classification Based on Hardness and Weathering [42]

Class	Hardness [1]	Diagnostic features ( ) = Weathering effects	Weathering grade [2]	Symbol	Strength, [3] t/ft^2
I	Extremely hard (or strong)	Rings under hammer impact; many blows required to break specimen. (No visible signs of decomposition or discoloration.)	Fresh	F	> 2500
II	Very hard to hard (or very strong)	Hand-held specimen breaks with hammer under more than one blow. (Slight discoloration inward from open fractures, otherwise similar to F.)	Slightly weathered	WS	2500-1000
III	Moderate (or medium strong)	Cannot be scraped or peeled with knife. Hand-held specimen can be broken with single moderate hammer blow. (Discoloration throughout; weaker minerals, such as feldspar, decomposed. Texture preserved.)	Moderately weathered	WM	500-250
IV	Soft (or weak)	Can just be scraped or peeled with knife. Indentations 1 to 3 mm show in specimen with moderate blow with pick end; lower strength specimens can be broken by hand with effort. (Most minerals somewhat decomposed; texture becoming indistinct but fabric preserved.)	Highly weathered	WH	250-50
V	Very soft (or very weak)	Material crumbles under moderate blow with pick and can be peeled with knife, but is hard to hand-trim for test specimen. (Minerals decompose to soil but fabric and structure preserved; i.e., saprolite.)	Completely weathered	WC	50-10
	Extremely soft or weak	Advanced state of decomposition	Residual	RS	<10

[1] Hardness depends on rock type, as well as weathering grade.
[2] Weathering grade applies primarily to crystalline rocks.
[3] Relationships to be considered only as a general guide, from U_c test.

Fracturing in rock is an important engineering parameter, and several methods are used to describe fracture occurrence. These methods are described in the paragraphs below.

12.7.1.1 Fracture Density

Fracture density is based on the spacing between all natural fractures in an exposure or core recovery lengths from drill hole, excluding mechanical breaks, shears, and shear zones.

12.7.1.2 Rock Quality Designation

Rock Quality Designation (RQD) is a fracture index used in many rock classification systems. To determine the RQD value, the total length (sum) of solid core that is 4 inches or more is divided by the length of the core run. RQD can also be determined from outcrops using data collected from detailed line surveys.

12.7.1.3 Rock Mass Rating

Rock Mass Rating (RMR) is geomechanical classification system for rock. RMR has wide application in engineering projects such as tunnels, slopes, foundations, and mines. Parameters used to classify a rock mass using the RMR system include:

- Uniaxial compressive strength of rock material
- RQD
- Spacing of discontinuities
- Condition of discontinuities
- Ground water conditions
- Orientation of discontinuities

12.8 Drilling and Sampling Methods

There are a great many methods of making exploratory holes or excavations. Sampling methods will vary according to the hardness of the material to be penetrated, the position of the ground water table, and the degree of sample disturbance that is acceptable.

12.8.1 Surface Sampling

Surface sampling can be made from: (1) dozer trenches, (2) backhoe test pits, or (3) outcrops [1, 4, 5]. Open test pits, trenches, tunnels, and shafts are accessible and afford the most complete information of the ground penetrated. They also may permit direct examination of the foundation rock. When the thickness of surficial deposits and ground water conditions permit their economical use, these methods are recommended for foundation exploration in addition to exploratory borings. In prospecting for embankment materials or concrete aggregate containing cobbles and boulders, open pits and trenches may be the only feasible means of obtaining required information. These methods are the only methods which permit accurate assessments of in-place conditions such as soil structure and small scale layering.

All *Reclamation Safety and Health Standards* [40] and Federal Occupational Safety and Health Administration requirements will be followed when conducting any sampling activities.

12.8.1.1 Test Pits and Trenches

Pits and trenches can be excavated quickly and economically by dozers, backhoes, scrapers, draglines, trenching machines, or ditching machines. Depths generally are less than 20 feet, and sides may require shoring if personnel must work in the excavations (greater than 4 feet deep). Final excavation to grade must be done carefully where samples will be obtained or in situ tests will be performed. Pits and trenches generally are used only above ground water level. Trench excavations are often used in fault evaluation studies, and mapping, sampling, and age testing can be performed in test pits and trenches. Shallow pits are commonly used for economical borrow area explorations.

The *Earth Manual* describes both hand and mechanical sampling methods commonly used to recover disturbed and undisturbed subsurface samples [1].

12.8.1.2 Exploratory Tunnels and Shafts

Exploratory tunnels and shafts permit sampling and testing of rock units and detailed examination of the geometry and physical properties of rock structures such as joints, faults, shear zones, and solution channels. They are commonly used to explore conditions at the location of large underground excavations, foundations, and abutments for large dams. They are particularly appropriate in defining the extent of marginal rock strength or adverse structure suspected from surface mapping and exploratory boring information. For major projects where high-intensity loads will be transmitted to foundations or abutments, tunnels or shafts afford the only practical means for testing in-place rock at locations and in directions corresponding to structural loading. Large vertical shafts are sometimes used when additional information is needed in deep channels or embankment foundations containing gravels, cobbles, and boulders. Shafts require casing, shoring, dewatering, lighting, and ventilation.

The *Earth Manual* describes sampling methods commonly used to recover disturbed and undisturbed samples in tunnels and shafts [1].

12.8.2 Auger Borings

Auger borings often provide one of the simplest methods of soil investigation and sampling (figure 12.8.2-1). Their use is described in test procedure USBR 7010 [9]. Auger borings can be by hand auger, solid-stem flight auger, bucket auger, or disk augers. Hand auger borings are useful in reconnaissance trips.

Figure 12.8.2-1. Typical hand augers used for soil sampling.

Solid-stem flight power augers (figure 12.8.2-2) provide a rapid method of procuring disturbed samples and are often used in borrow investigations where soil types are being confirmed or delineated.

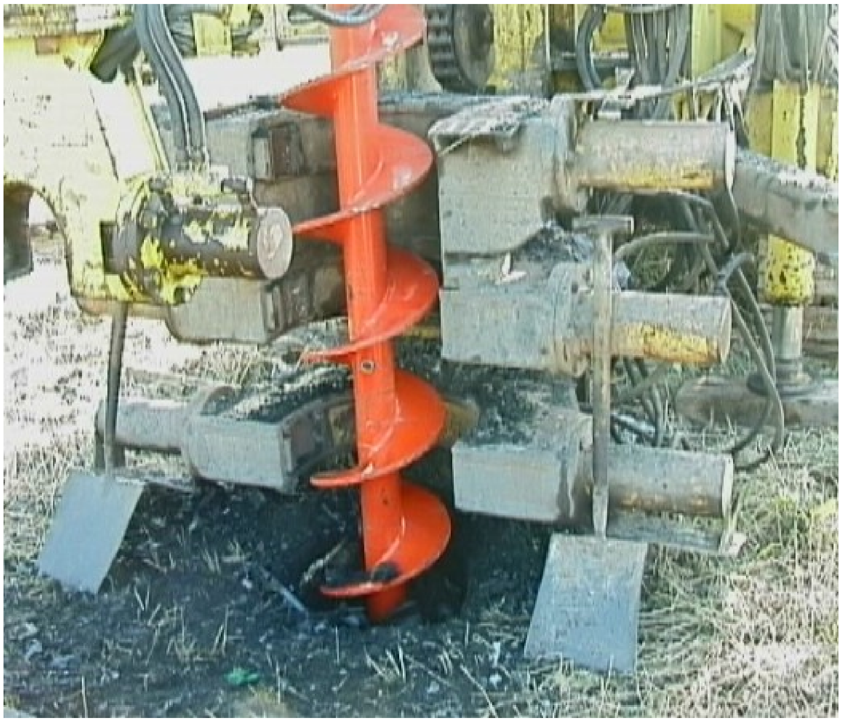


Figure 12.8.2-2. Solid-stem flight auger.

Solid-stem augers may be used for any purpose where disturbed samples are satisfactory and are valuable in advancing holes to depths at which undisturbed sampling by thin-walled tubes is required. Depths of auger investigations are usually limited by the ground water table and by the amount and maximum size of gravel, cobbles, and boulders as compared with the size of equipment used.

Bucket augers (figure 12.8.2-3) and disk augers are used where larger hole diameters or samples of coarser materials are needed. Large bucket augers are often used to sample gravelly soils for borrow purposes.

Bucket augers can also work below the water table; however, fine-grained material may be lost from the sampling slot. Large diameter disk augers (drilled shaft equipment) and casings are sometimes used for allowing accessible borings for logging and testing soils. Large diameter accessible borings are very expensive and rarely used, but they have been used on some earthquake liquefaction investigations, especially with gravelly soils.

Figure 12.8.2-3. Bucket auger being used with bentonite drilling mud.

Hollow-stem augers (figure 12.8.2-4) are used extensively by Reclamation and are especially preferred when drilling in existing dams.

Detailed procedures can be found in ASTM D 6151 [15]. These augers and samplers can be used very successfully in many soils below the water table. However, the system can have trouble in cohesionless soils that flow into the augers. In those deposits, it is necessary to maintain a high fluid level in the augers. Disturbed samples can be collected in a 5-foot-long, split barrel sampler housed inside the hollow stem. Hollow-stem augers have been developed where large diameter undisturbed samples can be obtained in acrylic liners mounted inside of the split barrel. Test procedure USBR 7105 [9] describes procedures for procuring undisturbed samples with the hollow-stem auger system.

Figure 12.8.2-4. Hollow-stem flight augers are extensively used by Reclamation.

12.8.3 Rotary Drilling

One of the most important tools for subsurface exploration for dams is the rotary drill (figure 12.8.3-1).

The rotary drill may be operated with a variety of bits and samplers, depending on the hardness of the material to be penetrated. Chapter 2 of the *Earth Manual* has an extensive, detailed discussion of drilling equipment [1]. Rotary drilling is most often used with a circulating medium (either water, drill mud, or air).

Drilling fluid with bentonite or polymer additives provides one of the best methods for drilling in unstable caving formations. Often, mud rotary drilling must be used in liquefaction investigations where penetration tests are performed in sands and the use of hollow-stem augers is unsuccessful. Fluid rotary drill, sample barrels, and cutting bits have been developed and used in many kinds of soil deposits. Double-tube core barrel samplers (Denison, Denver, and Pitcher) are capable of obtaining 5- to 6-inch-diameter undisturbed samples of sands, silts, or clays for laboratory testing, but their use has since fallen out of favor. The hollow-stem samplers are used more extensively today. Pure water is used as a circulating medium when water testing or installation of piezometers is required.

Figure 12.8.3-1. Upper Colorado Region's Gus Pech rotary drill rig.

Air rotary drills include drill-through casing drivers used with either rock bits or down-hole hammers and percussion drills (figure 12.8.3-2).

Figure 12.8.3-2. Air rotary drill and schematic of ODEX brand down-hole hammer and casing advancing system.

Drill-through casing advancers are used extensively by Reclamation where coarse soils, including cobbles and boulders, must be drilled. Air or air-foam can be used, but air-foam allows for better cuttings removal at lower circulation pressures. Straight air drilling requires high pressure and circulation velocities, and care must be taken to avoid fracturing in the borehole. Air drilling is not allowed in the core of an existing embankment dam. Percussion drills are normally used in rock quarry investigations where blast tests are required (figure 12.8.3-3).

Figure 12.8.3-3. Tracked air-percussion drill.

Diamond drilling of rock is a fluid rotary method performed to advance borings through rock and to procure core samples. The process is described in ASTM procedure D 2113 [22]. Polymer drill fluid is the best medium for procuring high quality samples and preserving bit life. Either conventional core barrels or wireline coring systems can be used, but wireline systems are favored in deep hole drilling because the method eliminates trips in and out of the hole with the drill rods. With the wireline technique, the core barrel is an integral part of the drill rod string. The drill rod serves as both a coring device and casing. Core samples are retrieved by removing the inner barrel assembly through the drill rod. This is accomplished by lowering an overshot or retriever, on a wireline, through the drill rod to release a locking mechanism built into the inner barrel head. The core is removed, the inner barrel is returned through the drill rod, and coring continues. Wireline systems can be used in water testing of rock formation. When drilling with water, core recovery may be poor in poor quality rock. Large diameter conventional core barrels are commonly used in drilling concrete where large diameter cores are required.

Small portable rotary drills operated by hand feed are used to procure core samples in accessible locations in rock or concrete. They use single tube masonary core barrels of variable diameters to relatively shallow depths. These drills can be used on foundation contacts in rock to confirm rock strengths.

12.8.4 Cable Tool and Churn or Wash Drilling/Boring

Most of Reclamation's early drilling, before the development of rotary drilling, was accomplished using wash boring or churn drilling techniques. This drilling method uses a tripod, motorized cat head, and a water pump. The equipment was compact and very portable. Hole advancement was accomplish by raising and lowering a chop or drive bit while jetting water. Casing could be driven to stabilize the borings to a limited extent because there was no reaction capability of the drill setup. Drive samples could be taken at selected intervals. This drilling method is not used often today due to the greater rotary drilling capability that exists.

Cable tool drilling is a unique method of churn drilling that uses larger mechanized equipment for heavier drill tooling and that enables deeper holes to be drilled for water wells (figure 12.8.4-1). Cable tool drilling is described in ASTM D 5875 [18].

The drilling method uses the same up and down drilling action of a drill/drive bit with much heavier tooling. Water is added to the hole to facilitate hole advancement. The only samples that are retrieved are slurry samples. This drilling method is not often used by Reclamation.

Figure 12.8.4-1. Bucyrus Erie Model 20W cable tool drill rig.

12.8.5 Undisturbed Sampling Methods

Fixed-piston samplers are used for undisturbed sampling of silty sands and silts that cannot be recovered by the thin-wall or open drive samplers. They are also preferred in soft to very soft clays. Sampling procedures are given in detail in USBR 7105 [9]. In sampling of these materials, suitable drilling mud and proper mud drilling techniques are necessary for obtaining satisfactory sample recovery. The sampler has the advantage of pushing through slough with the closed piston to the original cleanout depth for sampling. Figure 12.8.5-1 shows various soil samplers used with hollow-stem augers.

Figure 12.8.5-1. Several different types of soil samplers typically used in conjunction with hollow-stem augers.

12.8.6   Standard Penetration Test Borings

Penetration resistance testing and sampling of soil is a procedure to obtain a record of the resistance of soil to the penetration of a standard sampler under standard energy application and to obtain representative disturbed samples of the soil for identification purposes. The procedures for performing the test are contained in USBR 7015 [9]. The penetration resistance record is directly related to the in situ condition of the soil. The penetration resistance record and classification of representative samples can be used to develop site stratigraphy and identify zones where further investigations may be required.

The Standard Penetration Test (SPT) used as an indication of soil density also provides a sample (albeit a disturbed one). Further discussion is provided below in section 12.14.1.1.

12.8.7   Becker Hammer Drill

The Becker Penetration Test (BPT) is good for sampling gravelly soils (figure 12.8.7-1). The Becker hammer drill uses large diameter reverse circulation of air in the sampling mode and has a 3-inch-diameter inner casing to recover coarse gravel, cobble, and boulder formation samples in a cyclone. The casing is driven with a double acting pile driving hammer. Becker samples are disturbed, and sometimes the fines are lost in the sampling process.

Figure 12.8.7-1. Becker drill performing BPT in embankment and foundation materials.

12.8.8 Sonic Drilling

Sonic drilling has particular advantages for certain applications (figure 12.8.8-1). Sonic drilling practice is given in ASTM D 6914 [16]. Sonic drilling is a drilling technique that incorporates the use of high frequency vibrations to facilitate the drilling process. The drill stem and sampler barrel are vibrated at frequencies between about 50 and 180 hertz such that the sampler barrel normally advances by slicing through the soil. Sonic drills can penetrate very quickly and cope with a wide variety of substrates and formations, including soils with large boulders and rockfill embankments that preclude sampling by many other techniques. For core sampling, sonic drilling can be a highly effective tool allowing for the collection of very large, continuous, disturbed core samples. The sonic drill is also often used to rapidly advance borings for ground improvement projects. The method is favored for use in existing dams because the risk of hydraulic fracturing is minimized.

Figure 12.8.8-1. Sonic drill rig. The sonic drill head works by sending high frequency resonant vibrations down the drill string to the drill bit.

12.8.9 Standard Procedures for Drilling and Sampling in Existing Dams

Earth material investigations may be required in existing earth embankment dams. Reclamation developed standard procedures for drilling and sampling in existing dams. These procedures are general guidelines for both the Technical Service Center and field offices in the development and performance of embankment drilling programs. These guidelines reflect the need for care in the development and performance of embankment drilling programs. Reclamation's *Guidelines for Drilling and Sampling at Earth Embankment Dams* [13] provides detailed guidance policy on investigations in embankment dams, including investigation planning, site preparation, borehole advancement, subsurface testing, and borehole completion. There is a very real potential for damaging structures during the drilling process if these guidelines are not followed.

The primary concern is to minimize the potential for hydraulic fracturing. Considerable concern exists regarding drilling in embankment dams and the potential for hydraulic fracturing of the impervious barrier and some foundation materials during drilling. Certain embankment locations, materials, and conditions pose a higher potential for hydraulic fracturing than others, and improper drilling procedures will increase that potential for fracturing.

Reclamation guidelines provide a detailed listing of conditions in a dam where low stress zones may occur or where cracking of the impervious core may occur. These are areas prone to fracturing. The exploration team must carefully screen drilling locations to avoid these areas. There may also be areas where drilling may damage drainage zones with drill fluids and sealing materials. Drilling through pervious shell materials is of lesser concern.

Numerous drilling methods are available for drilling in embankments dams including methods using drilling fluids or air. Air drilling is of considerable concern and not allowed in the impervious core of dams. Drilling with fluids is also discouraged because fluid pressure can induce fracturing. Drilling methods that do not use fluids, such as hollow-stem auger, sonic drilling, and cable tool or churn drilling, are preferred methods for drilling in embankments. Selection of any one of, or a combination of, the aforementioned drilling methods should be based on site-specific conditions, hole utilization, economic considerations, availability of equipment, and careful review of the exploration program by experienced drill foreman, geologist, and geotechnical engineer members of the exploration team.

It is imperative that any drilling into the impervious core of an embankment dam or its foundation containing fine-grained soils must be performed by experienced drill crews that employ methods and procedures that minimize the potential for hydraulic fracturing. Therefore, it is essential that drillers be well trained and aware of the causes of, and the problems resulting from, hydraulic fracturing.

12.9 Logging of Explorations

12.9.1 Location of Explorations

The location of explorations is governed by their purpose. Initial explorations are usually for the purpose of clarifying geological conditions, and locations are governed primarily by geologic structure. Final explorations are completed primarily for engineering purposes and are located based on the engineering structure to be constructed. Every exploration should be definitely located in space. The exploration should be tied to the coordinate grid system and have a coordinate location, or be tied in some other satisfactory manner such as stationing or section ties, and its elevation at the top should be established. All explorations should be logged for the full depth; if, for any reason, a portion cannot be logged, the interval not logged must be recorded, along with an explanation stating the reason for omission. The orientation of angle holes must be recorded.

12.9.2 Identification of Explorations

To ensure completeness of the record and to eliminate confusion, explorations are normally numbered in the order they are excavated, and the numbering series should be continuous through the various stages of investigation. If an exploration is planned and programmed but not executed, it is preferable to maintain the hole number or test pit in the record as "not drilled" or "not excavated" with an explanatory note, rather than to reuse the exploration number elsewhere. It is permissible, however, to move explorations short distances when agreed to by the exploration team and retain the program number where such moves are required by local conditions or by changes in engineering plans. When exploration programs cover several areas, such as alternative dam sites and different borrow areas, a new series of numbers or appropriate suffixes for each site or borrow area should be used. A common practice is to include the year of the boring in the drill hole label (e.g., DH-12-01).

In addition to the feature designation, test explorations are usually prefixed with a two- or three-letter designation to describe the type of exploration. The following letter designations are frequently used in Reclamation:

DH - Drill Hole
AH - Auger Hole (hand)
AP - Auger Hole (power)
SPT - Standard Penetration Test

BPT - Becker Penetration Test
CPT - Cone Penetration Test
DN - Denison Sample Hole
TP - Test Pit
T - Trench
TT - Test Trench
CH - Churn Drill Hole
PT - Pitcher Sample Hole
PR - Penetration Resistance Hole
OW - Observation Well
BSH - Becker Sampling Hole
PRW - Pressure Relief Well
VST - Vane Shear Test boring

12.9.3 Log Forms

A log is the written record of the material properties and conditions occurring in individual explorations. It provides the fundamental facts on which all subsequent conclusions are based. Each log should be factual, accurate, clear, and complete. Depth to bedrock and to water level is valuable and important information and should always be reported.

When logging surficial deposits, every material type differing in composition from either the overlying or the underlying strata must be located by depth interval, including small lenses; be field classified; and be described in the log. Logs of explorations for structure foundations must indicate the depth of all lenses and layers of material and include the classification in addition to a detailed description of the material.

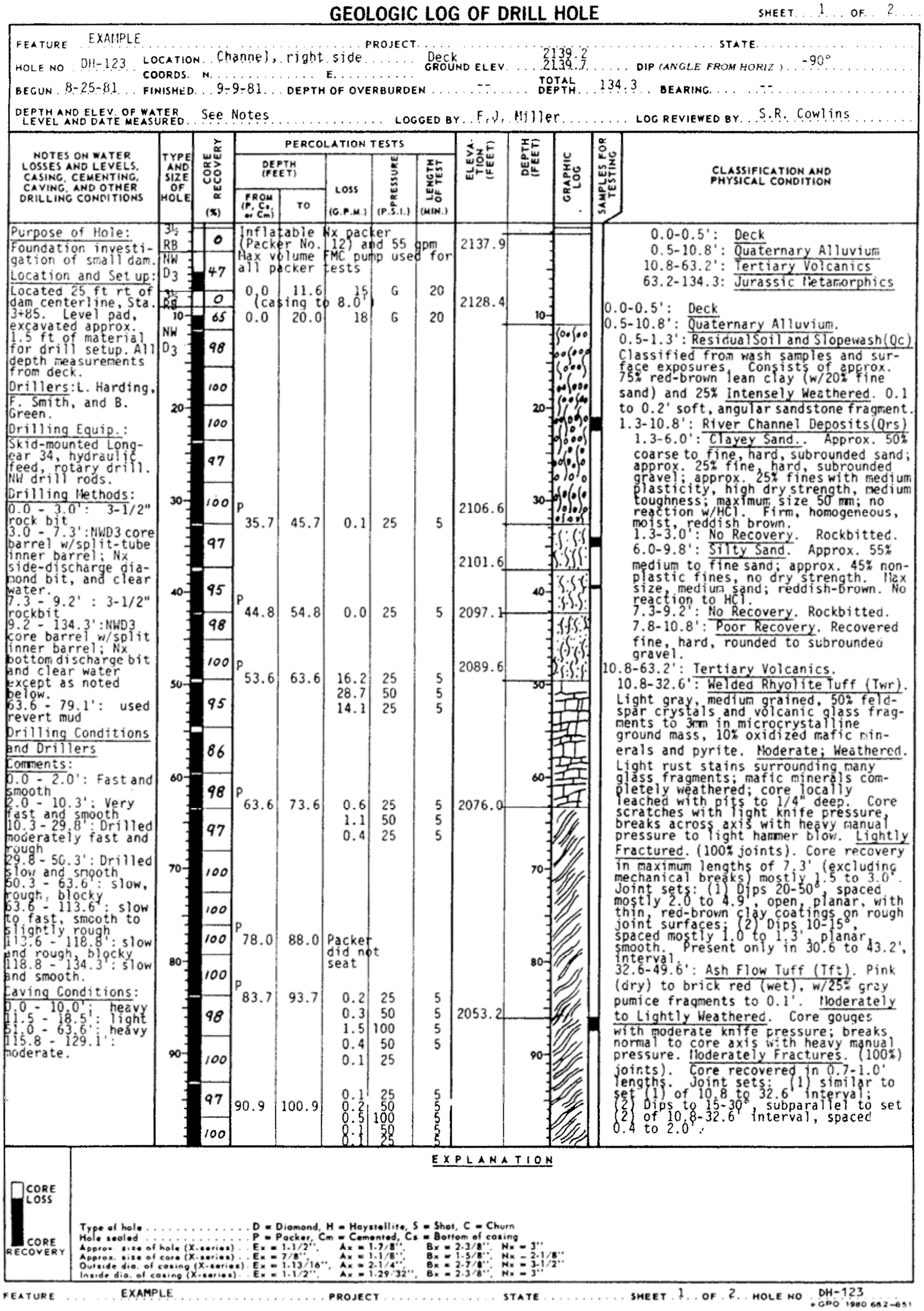
A log should always contain information on the size of the hole and on the type of equipment used for boring or excavating the hole, as well as the type of sampling equipment used. It should also include the kind of drilling equipment used on drill holes, a description of the penetrating equipment or type of auger used, or method of excavating test pits. Other important information to be recorded includes the type of drill fluid used, percent of drill fluid return, the size and depth of casing, and driller's comments. The location from which samples are collected should be indicated on the logs, and the amount of material recovered as core or undisturbed samples should be expressed as a percentage of each length of penetration of the barrel. Disturbed samples or core should be cleaned or scraped to reveal structure and be photographed immediately. The logs should also show the extent and the method of support used as the hole is deepened. Caving or squeezing material should be noted on the drill hole log because this may represent a low strength stratum. Wash sample intervals in surficial deposits should be identified as such and not given a soil classification.

Information on the presence or absence of water levels and comments on the reliability of these data should be given on all logs. Water levels should be recorded periodically from the time water is first encountered and as the hole is deepened and casing advanced. Water in the borehole should be bailed at the end of the drilling day and recorded at the beginning of the following day. Upon completion of drilling, the hole should, if possible, be bailed and allowed to recover in order to obtain the best practical water level measurement. Perched water tables and water under artesian pressure are very important to note. The extent of water-bearing units should be noted, and areas where water is lost as the boring proceeds should be reported. The log should contain information on any water tests made at intervals. See reference [4] and figures 12.9.3-1 and 12.9.3-2 for examples of a correctly filled out drill log. In some cases, it may be necessary to monitor seasonal ground water levels using piezometers installed in the boreholes.

Where cobbles and boulders are encountered in explorations for sources of embankment materials, it is important to determine their percentage by volume. In-place conditions should be noted for test pits but not for auger holes. Reliability of oversize estimation in auger holes is related to auger diameter and should be used with caution.

For test holes that penetrate less than the complete vertical extent of potential borrow material, a statement should be made under "Remarks" in the log, giving the reason for stopping the hole. For all other types of holes, a statement should be made at the end of the log that the work was completed as required or a statement explaining why the hole was terminated, such as reached predetermined depth, refusal, caving, etc.

Of critical importance, the log should always describe the reason for core loss intervals. Structure foundations have failed because core loss intervals were not described or understood; therefore, the designer was not aware of a foundation defect. For example, if 0.2 foot of core was not recovered in a 5- or 10-foot-long core run, the 0.2-foot core loss interval may well be the most important information recovered from that core run or, possibly, in the entire exploration. The core loss interval could represent a weakly cemented silty zone within a sandstone unit that was washed away by drill fluid/drilling action, or it could represent a low strength, soft clay or organic layer in a soil unit. Understanding and describing the core loss interval may require adding additional explorations or modifying drilling methods.



GEOLOGIC LOG OF DRILL HOLE SHEET 1 OF 2

FEATURE: EXAMPLE PROJECT: STATE:
HOLE NO: DH-123 LOCATION: Channel, right side COORDS. N. E.
GROUND ELEV: Deck 2139.2, 2139.7 DIP (ANGLE FROM HORIZ.): -90°
BEGUN: 8-25-81 FINISHED: 9-9-81 DEPTH OF OVERBURDEN: -- TOTAL DEPTH: 134.3 BEARING: --
DEPTH AND ELEV. OF WATER LEVEL AND DATE MEASURED: See Notes LOGGED BY: F.J. Miller LOG REVIEWED BY: S.R. Cowlins

NOTES ON WATER LOSSES AND LEVELS, CASING, CEMENTING, CAVING, AND OTHER DRILLING CONDITIONS

Purpose of Hole:
Foundation investigation of small dam.
Location and Set up:
Located 25 ft rt of dam centerline, Sta. 3+85. Level pad, excavated approx. 1.5 ft of material for drill setup. All depth measurements from deck.
Drillers: L. Harding, F. Smith, and B. Green.
Drilling Equip.:
Skid-mounted Longear 34, hydraulic feed, rotary drill. NW drill rods.
Drilling Methods:
0.0 - 3.0': 3-1/2" rock bit
3.0 - 7.3': NWD3 core barrel w/split-tube inner barrel; Nx side-discharge diamond bit, and clear water.
7.3 - 9.2' : 3-1/2" rockbit
9.2 - 134.3': NWD3 core barrel w/split inner barrel; Nx bottom discharge bit and clear water except as noted below.
63.6 - 79.1': used revert mud
Drilling Conditions and Drillers Comments:
0.0 - 2.0': Fast and smooth
2.0 - 10.3': Very fast and smooth
10.3 - 29.8': Drilled moderately fast and rough
29.8 - 50.3': Drilled slow and smooth
50.3 - 63.6': slow, rough, blocky
63.6 - 113.6': slow to fast, smooth to slightly rough
113.6 - 118.8': slow and rough, blocky
118.8 - 134.3': slow and smooth.
Caving Conditions:
0.0 - 10.0': heavy
11.5 - 18.5': light
51.0 - 63.6': heavy
115.8 - 129.1': moderate.

TYPE AND SIZE OF HOLE: 3½ RB; NW D3; 3½ RB; NW D3

CORE RECOVERY (%): 0, 47, 0, 65, 98, 100, 100, 97, 100, 97, 95, 98, 100, 95, 86, 98, 97, 100, 100, 100, 100, 98, 100, 97, 100

PERCOLATION TESTS

Inflatable Nx packer (Packer No. 12) and 55 gpm Max volume FMC pump used for all packer tests

Depth From (P, Cs, or Cm)	Depth To	Loss (G.P.M.)	Pressure (P.S.I.)	Length of Test (Min.)
0.0 (casing to 8.0')	11.6	15	G	20
0.0	20.0	18	G	20
P 35.7	45.7	0.1	25	5
P 44.8	54.8	0.0	25	5
P 53.6	63.6	16.2	25	5
		28.7	50	5
		14.1	25	5
P 63.6	73.6	0.6	25	5
		1.1	50	5
		0.4	25	5
P 78.0	88.0	Packer did not seat		
P 83.7	93.7	0.2	25	5
		0.3	50	5
		1.5	100	5
		0.4	50	5
		0.1	25	
90.9	100.9	0.1	25	5
		0.2	50	5
		0.5	100	5
		0.1	50	5
		0.1	25	5

ELEVATION (FEET): 2137.9, 2128.4, 2106.6, 2101.6, 2097.1, 2089.6, 2076.0, 2053.2

DEPTH (FEET): 10, 20, 30, 40, 50, 60, 70, 80, 90

CLASSIFICATION AND PHYSICAL CONDITION

0.0-0.5': Deck
0.5-10.8': Quaternary Alluvium
10.8-63.2': Tertiary Volcanics
63.2-134.3: Jurassic Metamorphics

0.0-0.5': Deck
0.5-10.8': Quaternary Alluvium.
0.5-1.3': Residual Soil and Slopewash (Qc) Classified from wash samples and surface exposures. Consists of approx. 75% red-brown lean clay (w/20% fine sand) and 25% Intensely Weathered. 0.1 to 0.2' soft, angular sandstone fragment.
1.3-10.8': River Channel Deposits (Qrs)
1.3-6.0': Clayey Sand.. Approx. 50% coarse to fine, hard, subrounded sand; approx. 25% fine, hard, subrounded gravel; approx. 25% fines with medium plasticity, high dry strength, medium toughness; maximum size 50 mm; no reaction w/HCl. Firm, homogeneous, moist, reddish brown.
1.3-3.0': No Recovery. Rockbitted.
6.0-9.8': Silty Sand. Approx. 55% medium to fine sand; approx. 45% nonplastic fines, no dry strength. Max size, medium sand; reddish-brown. No reaction to HCl.
7.3-9.2': No Recovery. Rockbitted.
7.8-10.8': Poor Recovery. Recovered fine, hard, rounded to subrounded gravel.
10.8-63.2': Tertiary Volcanics.
10.8-32.6': Welded Rhyolite Tuff (Twr). Light gray, medium grained, 50% feldspar crystals and volcanic glass fragments to 3mm in microcrystalline ground mass, 10% oxidized mafic minerals and pyrite. Moderate; Weathered. Light rust stains surrounding many glass fragments; mafic minerals completely weathered; core locally leached with pits to 1/4" deep. Core scratches with light knife pressure, breaks across axis with heavy manual pressure to light hammer blow. Lightly Fractured. (100% joints). Core recovery in maximum lengths of 7.3' (excluding mechanical breaks) mostly 1.5 to 3.0'. Joint sets: (1) Dips 20-50°, spaced mostly 2.0 to 4.9', open, planar, with thin, red-brown clay coatings on rough joint surfaces; (2) Dips 10-15°, spaced mostly 1.0 to 1.3', planar, smooth. Present only in 30.6 to 43.2', interval.
32.6-49.6': Ash Flow Tuff (Tft). Pink (dry) to brick red (wet), w/25% gray pumice fragments to 0.1'. Moderately to Lightly Weathered. Core gouges with moderate knife pressure; breaks normal to core axis with heavy manual pressure. Moderately Fractures. (100%) joints). Core recovered in 0.7-1.0' lengths. Joint sets: (1) similar to set (1) of 10.8 to 32.6' interval; (2) Dips to 15-30°, subparallel to set (2) of 10.8-32.6' interval, spaced 0.4 to 2.0'.

EXPLANATION

CORE LOSS
CORE RECOVERY

Type of hole . . . D = Diamond, H = Haystellite, S = Shot, C = Churn
Hole sealed . . . P = Packer, Cm = Cemented, Cs = Bottom of casing
Approx. size of hole (X-series) . . Ex = 1-1/2", Ax = 1-7/8", Bx = 2-3/8", Nx = 3"
Approx. size of core (X-series) . . Ex = 7/8", Ax = 1-1/8", Bx = 1-5/8", Nx = 2-1/8"
Outside dia. of casing (X-series) . Ex = 1-13/16", Ax = 2-1/4", Bx = 2-7/8", Nx = 3-1/2"
Inside dia. of casing (X-series) . Ex = 1-1/2", Ax = 1-29/32", Bx = 2-3/8", Nx = 3"

FEATURE: EXAMPLE PROJECT: STATE: SHEET 1 OF 2 HOLE NO DH-123
GPO 1980 682-851

Figure 12.9.3-1 Example geologic log of a drill hole.

STANDARD PENETRATION TEST HOLE NO. DH-400

SHEET 1 OF 3

PROJECT EXAMPLE FEATURE EXAMPLE AREA EXAMPLE STATE EXAMPLE

COORDS. N. 10653 E. 10003 GROUND ELEV 6742.5 ANGLE FROM HORIZ 90.0 DOWN

BEGUN 06-16-84 FINISHED 06-19-84 DEPTH TO BEDROCK 80.4 TOTAL DEPTH 80.4 BEARING

DEPTH TO WATER SEE NOTES LOGGED BY JOHN DOE REVIEWED BY JANE DOE

NOTES

PURPOSE:
FOUNDATION INVESTIGATION FOR PUMPING PLANT "X"

DRILL EQUIPMENT:
MOBIL B40-L TRUCK MOUNTED DRILL WITH BEAN 20 WATER PUMP

DRILLER:
JACK DOE

DRILLING METHOD:
0.0-80.4FT:
DRILLED WITH 2-7/8IN TRICONE ROLLER ROCK BIT USING BENTONITE AND WATER AS DRILLING FLUID WITH 50 SEC AVG FUNNEL VISCOSITY. PEFORMED SPT'S APPROX 5FT INTERVALS USING A 1-3/8IN ID SPLIT BARREL SAMPLER ON NW DRILL RODS WITH A 140 LBM DOM SAFETY HAMMER (TOTAL MASS 235 LBM) AND A 30IN DROP. NX CASING ADVANCED ON 5FT INTERVALS FOLLOWING SPT'S AND CLEANED OUT WITH ROCK BIT

SAMPLE INTERVAL NOTES:

15.0-16.5FT: DRILL STRING SANK THROUGH 0.2FT OF THE SEATING INTERVAL UNDER WEIGHT OF HAMMER AND RODS

20.0-21.5FT: DRILL STRING SANK 0.7FT THROUGH DRIVE INTERVAL, 0.2FT UNDER RODS AND 0.5FT UNDER RODS AND HAMMER

25.0-26.5FT: DRILL STRING SANK 1.2FT THROUGH DRIVE INTERVAL, 0.4FT-RODS, 0.8FT-RODS AND HAMMER. DRILLING DISTURBANCE NOT APPARENT

30.0-31.7FT: DRILL STRING SANK 1.7FT BELOW CLEANOUT DEPTH 0.5FT-RODS, 1.2FT RODS AND HAMMER. DRILLING DISTRUBANCE NOT APPARENT

35.0-36.5FT: UNEVEN PENETRATION, 28LOWS IN 0.5-1.0FT INT., 98LOWS INT. 0-1.5FT INT. PENETRATION DECREASED AT 1.1FT

45.0-46.5FT: UNEVEN PENETRATION-8BLOWS IN 0.5-1.0FT INT. 20 BLOWS IN 1.0-1.5FT INT. PENETRATION DECREASED AT 1.1FT

55.0-56.5FT: 0.4FT OF SLOUGH, SAMPLER VENT PORT PLUGGED WITH SAND POSSIBLE UNRELIABLE N VALUE

65.0-66.3FT: REACHED 50BLOWS IN THE DRIVE INTERVAL AT 1.3 FT. 5 BLOWS IN SEATING INTERVAL, 25 BLOWS IN 0.5-1.0FT, 20 BLOWS IN 1.0-1.3FT. DRIVING IN GRAVELS

70.0-71.2FT: STOPPED TEST AFTER 50BLOWS. POSSIBLE JETTING DISTURBANCE, 10 BLOWS IN

STANDARD PENETRATION TEST (DESIGNATION E-21, EARTH MANUAL) — BLOWS PER FOOT: 140 LB. HAMMER-30 IN. DROP (10, 20, 30, 40)

PERCENT CORE RECOVERY	NUMBER OF BLOWS	PERCENT MOISTURE
85	8	38.1
90	10	28.7
92	3	34.3
94	2	34.3
91	* 1	45.6
95	* 0	46.4
89	11	*27.7
65	21	18.4
85	28	*32.5
80	17	*28.5
95	* 25	21.3
88	14	*28.6
80	*50/1.3	*23.7
40	*50/1.2	*24.3
	*50/.4	
	*10/.1	

DEPTH SCALE (FEET): 10, 20, 30, 40, 50, 60, 70, 80, 90

CLASSIFICATION INTERVALS — ELEVATIONS (FEET): 6737.5, 6706.0, 6702.5

CLASSIFICATION AND PHYSICAL CONDITION

0.0-36.5 QUATERNARY LACUSTRINE SEDIMENTS (QL)

0.0-5.0: ROCK BIT INTERVAL; LEAN TO FAT CLAY WITH ORGANIC MATERIAL, VEGATATION AND ROOTS. DESCRIPTION BASED ON DRILLING CONDITION AND CUTTINGS RETURN

5.0-6.5: SPT SAMPLE
5.0-5.8: LEAN CLAY (CL): APPROX. 85% FINES WITH MEDIUM PLASTICITY, MEDIUM TOUGHNESS, HIGH DRY STRENGTH; APPROX. 15% PREDOMINANTLY FINE SAND; MAXIMUM SIZE, COARSE SAND; WEAK REACTION WITH HCL. - MOIST, TAN, FIRM, HOMOGENEOUS, ROOTS AND ORGANIC MATERIALS PRESENT

5.8-6.5: FAT CLAY (CH): APPROX. 95% FINES WITH HIGH PLASTICITY, HIGH TOUGNESS, VERY HIGH DRY STRENGTH; APPROX. 5% PREDOMINANTLY FINE SAND; MAXIMUM SIZE, FINE SAND; WEAK REACTION WITH HCL. - MOIST, TAN, FIRM TO SOFT, HOMOGENEOUS, SOME ROOTS PRESENT

6.5-10.0: ROCK BIT INTERVAL; SILTS AND CLAYS. DESCRIPTION BASED ON DRILLING CONDITION AND CUTTINGS RETURN

10.0-11.5: SPT SAMPLE
CLAYEY SILT (ML-CL): APPROX. 90% FINES WITH LOW PLASTICITY, LOW TOUGHNESS, LOW DRY STRENGTH; APPROX. 10% PREDOMINANTLY FINE SAND; MAXIMUM SIZE, FINE SAND; WEAK REACTION WITH HCL. - MOIST, GREY, SOFT, LAMINATED

11.5-15.0: ROCK BIT INTERVAL, LEAN TO FAT CLAYS BASED ON DRILLING CONDITION AND CUTTINGS RETURN

15.0-16.5: SPT SAMPLE
LEAN TO FAT CLAY (CL-CH): APPROX. 95% FINES WITH MEDIUM TO HIGH PLASTICITY, MEDIUM TO HIGH TOUGHNESS, VERY HIGH DRY STENGTH; APPROX. 5% PREDOMINANTLY FINE SAND; MAXIMUM SIZE, FINE SAND; WEAK REACTION WITH HCL. - WET, GREY-TAN, SOFT, LAMINATED

16.5-20.0 ROCK BIT INTERVAL; LEAN TO FAT CLAYS. DESCRIPTION BASED ON DRILLING CONDITION AND CUTTINGS RETURN

20.0-21.5: SPT SAMPLE
FAT CLAY (CH): APPROX. 100% FINES WITH HIGH PLASTICITY, HIGH TOUGHNESS, VERY HIGH DRY STRENGTH; WEAK REACTION WITH HCL. - WET, GREY, VERY SOFT TO SOFT, LAMINATED

21.5-25.0: ROCK BIT INTERVAL; FAT CLAYS, VERY SOFT, DESCRIPTION BASED ON DRILLING CONDITION AND CUTTINGS RETURN

25.0-26.5: SPT SAMPLE
FAT CLAY (CH): APPROX. 100% FINES WITH HIGH PLASTICITY, HIGH TOUGHNESS, VERY HIGH DRY STRENGTH; WEAK REACTION WITH HCL. - VERY WET, GREY, VERY SOFT, LAMINATED.

26.5-30.0: ROCK BIT INTERVAL; FAT CLAYS, VERY SOFT, BASED ON DRILLING CONDITION AND CUTTINGS RETURN

30.0-31.7: SPT SAMPLE
FAT CLAY (CH): APPROX. 100% FINES WITH HIGH PLASTICITY, HIGH TOUGHNESS, VERY HIGH DRY STRENGTH; WEAK REACTION WITH HCL. - VERY WET, GREY-BLACK, VERY SOFT, HOMOGENEOUS

31.7-35.0: ROCK BIT INTERVAL; FAT CLAYS, VERY SOFT HIGH PLASTICITY, BASED ON DRILLING CONDITION AND CUTTINGS RETURN.

35.0-36.5: SPT SAMPLE
35.0-36.0: FAT CLAY (CH): APPROX. 100% FINES WITH HIGH PLASTICITY, HIGH TOUGHNESS, VERY HIGH DRY STRENGTH; WEAK REACTION WITH HCL. - WET, GREY-TAN, SOFT, LAMINATED. *MOISTURE 43.2

36.0-36.5: CLAYEY SAND (SC): APPROX. 70% FINE TO MEDIUM, HARD, SUBANGULAR SAND; APPROX. 30% FINES WITH HIGH PLASTICITY, HIGH TOUGHNESS, HIGH DRY STRENGTH; MAXIMUM SIZE, COARSE SAND; WEAK REACTION WITH HCL. - MOIST, GREY, DENSE, HOMOGENEOUS, FINES CONTENT IS HIGHER AT CONTACT. *MOISTURE 27.7%

36.5-80.4: QUATERNARY ALLUVIUM (QAL)

36.5-40.0: ROCK BIT INTERVAL; CLAYEY TO SILTY

COMMENTS:

*-NEXT TO N VALUE, SEE NOTES COLUMN
*-NEXT TO MOISTURE, SEE CLASS DESCRIPTION COLUMN
INCLASS-DESCRIPTION COLUMN INDICATES DESCRIPTION OF INPLACE CONDITION WILL FOLLOW

INT=INTERVAL
GRD=GROUND SURFACE

EXPLANATIONS:

BLOWS/FOOT — RECORD NUMBER OF BLOWS REQUIRED FOR ONE FOOT OF PENETRATION. IF 50 BLOWS RESULT IN LESS THAN ONE FOOT OF PENETRATION, RECORD DEPTH PENETRATED; THUS, 50/.4 INDICATES 0.4 FOOT PENETRATED WITH 50 BLOWS.

Figure 12.9.3-2 Example geologic log of a penetration resistance drill hole.

12.9.4 Description of Soils

The person logging exploratory holes should be able to identify and classify soils according to the USCS. The description of a soil in a log should include its typical name, followed by pertinent descriptive data. After the soil is described, it should be placed in the appropriate soil classification group by use of USCS letter symbols. Identification and classification of soils in logs of explorations should be based on visual examination and manual tests. Field logs are not required to contain refinements that can be determined only by use of laboratory equipment. All soils should be visually classified in the field and descriptions included on the logs. This is because the logger may see features in the soil that are important and would be destroyed if laboratory tests were run. Standard practice is to include lab data on the log forms separately. The purposes for which soils are investigated for embankment dams can be divided into two categories: (1) borrow materials for embankments, concrete aggregate, or backfill; and (2) foundations for the dam and appurtenant structures. See figures 12.9.4-1 through 12.9.4-4 for logs of test pit or auger hole. See reference [41; section 12.5.1] for a detailed description.

Soils that are potential sources of borrow material for embankments must be described adequately in the log of the exploratory test pit or auger hole log. The recording of their natural water content is important. For simplicity, the natural moisture content of borrow soils should be reported as dry, moist, or wet.

When soils are being explored as foundations for dams and appurtenant works, their natural structure, consistency, and moisture content are of outstanding importance. Test pit logs of foundation explorations must emphasize the in-place condition of a soil in addition to describing its constituents. The natural state of foundation soils is significant because bearing capacity and settlement under load vary tremendously with the consistency or compactness of the soil. Therefore, information that a clay soil is hard and dry, or soft and moist, is important. Correct classification is needed so that the effect of moisture changes on foundation properties can be assessed. The use of a general type name, such as loess, caliche, etc., in addition to the soil classification name, when known, may be helpful in identifying in-place conditions. Logs of soils in foundations and borrow areas should have geologic units assigned for correlation and interpretation.

Descriptions of manmade or processed materials, as shown on figure 12.9.4-4, must first include the name of the material and then the USCS classification so that contractors bidding on projects understand the project conditions correctly.

7-1336-A (1-86) Bureau of Reclamation	LOG OF TEST PIT OR AUGER HOLE	HOLE NO.

FEATURE ______ PROJECT ______
AREA DESIGNATION ______ GROUND ELEVATION ______
COORDINATES N ______ E ______ METHOD OF EXPLORATION ______
APPROXIMATE DIMENSIONS ______ LOGGED BY ______
DEPTH WATER ENCOUNTERED 1/ ______ DATE ______ DATE(S) LOGGED ______

CLASSIFICATION GROUP SYMBOL (describe sample taken)	CLASSIFICATION AND DESCRIPTION OF MATERIAL SEE USBR 5000, 5005	% PLUS 3 in (BY VOLUME) 3 - 5 in	5 - 12 in	PLUS 12 in
(GW)scb 7.4 ft	0.0 to 7.4 ft WELL-GRADED GRAVEL WITH SAND, COBBLES, AND BOULDERS: About 70% coarse to fine, hard, subrounded gravel; about 30% coarse to fine, hard, subangular sand; trace of fines; no reaction with HCl. TOTAL SAMPLE (BY VOLUME): 22% 3- to 5-inch hard, subrounded cobbles; 14% 5- to 12-inch hard, rounded cobbles; 2 percent plus 12-inch hard, subrounded boulders; remainder minus 3-inch; maximum dimension, 400 mm. IN-PLACE CONDITION: homogeneous, dry, brown GEOLOGIC INTERPRETATION: alluvial fan	22	14	2

REMARKS.

SOIL WITH MEASURED PERCENTAGES
OF COBBLES AND BOULDERS

1/ Report to nearest 0.1 foot

GPO 849-366

Figure 12.9.4-1 Log of test pit or auger hole—abbreviated soil classification group symbols for soil with cobbles and boulders.

7-1336-A (1-86)
Bureau of Reclamation

LOG OF TEST PIT OR AUGER HOLE

HOLE NO. ______

FEATURE Example
AREA DESIGNATION
COORDINATES N ______ E ______
APPROXIMATE DIMENSIONS
DEPTH WATER ENCOUNTERED 1/ ______ DATE ______

PROJECT
GROUND ELEVATION
METHOD OF EXPLORATION
LOGGED BY
DATE(S) LOGGED

CLASSIFICATION GROUP SYMBOL (describe sample taken)	CLASSIFICATION AND DESCRIPTION OF MATERIAL SEE USBR 5000, 5005	% PLUS 3 in (BY VOLUME) 3 - 5 in	5 - 12 in	PLUS 12 in
CL three sack samples 4.2 ft	0.0 to 4.2 ft LEAN CLAY: About 90% fines with medium plasticity, high dry strength, medium toughness; about 10% predominantly fine sand; maximum size, medium sand; strong reaction with HCl. IN-PLACE CONDITION: Soft, homogeneous, wet, brown. Three 50-lbm sack samples taken from 12-inch-wide sampling trench for entire interval on north side of test pit. Samples mixed and quartered.			
(SC)g block sample 9.8 ft	4.2 to 9.8 ft CLAYEY SAND WITH GRAVEL: About 50% coarse to fine, hard, subangular to subrounded sand; about 25% fine, hard, subangular to subrounded gravel; about 25% fines with medium plasticity, high dry strength, medium toughness; maximum size, 20 mm; weak reaction with HCl. IN-PLACE CONDITION: homogeneous except for occasional lenses of clean fine sand 1/4 inch to 1 inch thick, moist, reddish-brown. 12- by 12-inch block sample taken at 6.0 to 7.0 ft depth, at center of south side of test pit.			

REMARKS:

TEST PIT WITH SAMPLES TAKEN

1/ Report to nearest 0.1 foot

GPO 849-366

Figure 12.9.4-2 Log of test pit or auger hole—in-place conditions and sampling.

7-1336-A (1-86)
Bureau of Reclamation

LOG OF TEST PIT OR AUGER HOLE

HOLE NO. ______

FEATURE ______ PROJECT ______
AREA DESIGNATION ______ GROUND ELEVATION ______
COORDINATES N ______ E ______ METHOD OF EXPLORATION ______
APPROXIMATE DIMENSIONS ______ LOGGED BY ______
DEPTH WATER ENCOUNTERED 1/ ______ DATE ______ DATE(S) LOGGED ______

CLASSIFICATION GROUP SYMBOL (describe sample taken)	CLASSIFICATION AND DESCRIPTION OF MATERIAL SEE USBR 5000, 5005	% PLUS 3 in (BY VOLUME) 3-5 in	5-12 in	PLUS 12 in
GP (visual) GW (lab classif) three sack sample 3.2 ft	0.0 to 3.2 ft POORLY GRADED GRAVEL WITH SAND: About 70% coarse to fine, hard, subangular gravel; about 30% coarse to fine, hard, subangular sand; trace of fines; maximum size, 75 mm; no reaction with HCl. IN-PLACE CONDITION: homogeneous, moist, brown LAB TEST DATA: Sample had 64% gravel, 34% sand, 2% fines, Cu = 24, Cc = 1.8 Laboratory classification is WELL-GRADED GRAVEL WITH SAND. Three 50-lbm sack sample taken for testing from 18-inch-wide sampling trench for entire depth interval on east side of trench. Material mixed and quartered to get sample.			
CL (lab classif) one sack sample 7.6 ft	3.2 to 7.6 ft LEAN CLAY: About 90% fines with medium plasticity, high dry strength, medium toughness; about 10% predominantly fine sand; maxiumum size coarse sand; no reaction with HCl. IN-PLACE CONDITION: Firm, homogeneous, moist, yellowish-brown. LAB TEST DATA: 86% fines, 14% sand, LL = 36, PI = 19 One 40-lbm sack sample taken for testing from 12-inch-wide sampling trench from 4.7 to 6.8 ft depth.			

REMARKS:

REPORTING LABORATORY CLASSIFICATION IN
ADDITION TO VISUAL CLASSIFICATION

1/ Report to nearest 0.1 foot

GPO 849-366

Figure 12.9.4-3 Log of test pit or auger hole—combined laboratory and visual classification.

7-1336 A (1-86)
Bureau of Reclamation

LOG OF TEST PIT OR AUGER HOLE

HOLE NO. ____________

FEATURE ____________ PROJECT ____________
AREA DESIGNATION ____________ GROUND ELEVATION ____________
COORDINATES N ____________ E ____________ METHOD OF EXPLORATION ____________
APPROXIMATE DIMENSIONS ____________ LOGGED BY ____________
DEPTH WATER ENCOUNTERED 1/ ____________ DATE ____________ DATE(S) LOGGED ____________

CLASSIFICATION GROUP SYMBOL (describe sample taken)	CLASSIFICATION AND DESCRIPTION OF MATERIAL SEE USBR 5000, 5005	% PLUS 3 in (BY VOLUME) 3 - 5 in	5 - 12 in	PLUS 12 in
SHALE CHUNKS 12.6 ft	11.2 to 12.6 ft SHALE CHUNKS: Retrieved as 2- to 4-inch pieces of shale from power auger hole, dry, brown, no reaction with HCl. After slaking in water for 24 hours, material identified as "SANDY LEAN CLAY (CL)" - About 60 percent fines with medium plasticity, high dry strength, no dilatancy, medium toughness; about 35 percent fine to medium sand; about 5% gravel-size pieces of shale			
CRUSHED SANDSTONE Bin No. 3	Bin No. 3 CRUSHED SANDSTONE: Product of commercial crushing operation; "POORLY GRADED SAND WITH SILT (SP-SM)" - About 90% fine to medium sand; about 10% nonplastic fines; maximum size, medium sand; dry, reddish-brown; strong reaction with HCl.			
CRUSHED ROCK NE Stockpile	NE Stockpile CRUSHED ROCK: Processed from gravel and cobbles in Pit No. 7; "POORLY GRADED GRAVEL (GP)" - About 90% fine, hard, angular gravel-size particles; about 10% coarse, hard, angular sand-size particles; maximum size, 19 mm; dry, tan; no reaction with HCl.			
BROKEN SHELLS 3.2 ft	0.0 to 3.2 ft BROKEN SHELLS: Natural deposit of shells; "POORLY GRADED GRAVEL WITH SAND (GP)" - About 60% gravel-size broken shells; about 35% sand and sand-size shell pieces; about 5% fines.			

REMARKS:

MATERIALS OTHER THAN NATURAL SOILS

1/ Report to nearest 0.1 foot

GPO 849-366

Figure 12.9.4-4 Log of test pit or auger hole—materials other than natural soils.

12.9.5 Description of Rock Cores

The basic objective of describing rock cores is to provide a concise record of the important geologic and physical characteristics of the core materials. The description should be prepared by a geologist; its usefulness will depend largely upon the individual's experience in logging rock core for engineering purposes and their knowledge of engineering geology.

Descriptions of bedrock should include the formation name and age, if known or possible to determine; distribution and dimensional characteristics; and a description of generalized lithologic, physical features, and characteristics that could affect strength or permeability. This includes bedding/foliation/flow texture, weathering, hardness/strength, contacts, discontinuities (includes fracture indexes), permeability data, and moisture conditions. The *Engineering Geology Field Manual* shows the format for describing rock in exploration logs and legends on general note drawings [4].

12.10 Borehole Examination

Interpretation of subsurface conditions solely by observation, study, and testing of rock core samples recovered from core borings often imposes an unnecessary limitation on obtaining the best possible picture of site geology. The sidewalls of the borehole from which the core has been extracted offer a unique picture of the subsurface where all structural features of the rock formation are still in their original position. This view of the rock can be important, particularly when portions of rock core have been lost during the drilling operation and when the true dip and strike of structural features are difficult to obtain from the core. Borehole observation and photographic equipment includes borehole television (TV) and still cameras, sonic imagery loggers, and alignment survey devices.

For information on available services, equipment, and equipment capabilities and requirements for geophysical investigations, refer to chapter 14 of the *Engineering Geology Field Manual* [6].

Borehole cameras that have limited focus capability are satisfactory for examining features on the sidewalls of a borehole. However, the small viewing area and limited focus reduce their usefulness in borings that have cavities extending some distance into the sidewalls. They are best used for examining soft or geologic structure zones for which cores may not have been recovered and for determining the dip and strike of discontinuities in the foundation. Borescopes have limited use because of their small viewing area, limited depth capability, and cumbersome operation, but they are relatively inexpensive to use [6].

The TV camera has variable focus and is suitable for examining both structural features and the nature and approximate dimensions of caved sections of clean open boreholes or boreholes filled with clear water. The sonic imagery (televiewer) system uses acoustic pulses to produce a borehole wall image and can be used in a hole filled with drilling mud. The TV camera is used to examine cavities in rock such as solution voids in calcareous formations, open cooling joints and lava tunnels in volcanic rocks, pipelines, mines, tunnels, and shafts. The televiewer can be used to distinguish and obtain the orientation of fractures, soft materials, cavities, and other discontinuities. Changes in lithology and porosity may also be distinguished [6].

The borehole optical televiewer survey provides a continuous, detailed, and oriented 360-degree image of the borehole walls using a unique optical imaging system that records a reflection of the borehole wall in a conic mirror (figure 12.10-1). The borehole optical televiewer is used in open boreholes or in boreholes filled with clean water to obtain a complete fracture analysis that includes dip, strike, frequency, and aperture.

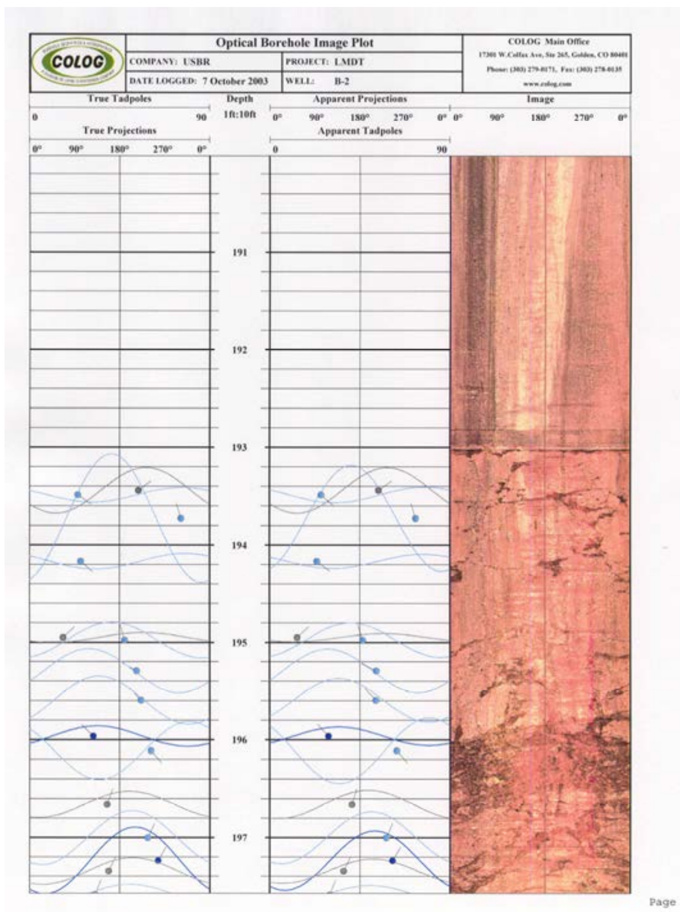


Figure 12.10-1. Example of image plot from a borehole optical televiewer. Image of borehole is at right, and orientations of discontinuities are on the left.

In addition, lithological characterization, detection of thin beds and bedding dip, casing inspection, and true-color imaging are provided.

Alignment surveys are often necessary when the plumbness and/or orientation of a hole is important. An instrument is lowered down the borehole to determine the amount and direction of deviation from vertical. This factor may be critical in deep holes where instrumentation packages are to be installed or where precise determinations of structural features in the rock are required [6].

12.11 Borrow Investigation for Dam Construction

Borrow investigations for new dams or rehabilitation of old dams must be comprehensive and define the full extent of the available materials for the designer and construction contractor. Typical materials to be located include impervious core, shell, drainage materials, and slope protection. For dam rehabilitations with stability berms, there may be no specific soil type requirements because the berm is just a stabilizing mass. It is not sufficient to just locate the volume of material needed in the design. Instead, it is recommended to locate two to three times the material needed for construction. Borrow investigations include determinations of waste materials and oversize materials. For new dams, the borrow soils are often located within the proposed reservoir site for economical haul distance and to minimize environmental impact.

Figure 12.11-1shows an example of a borrow exploration. Note that there are many tools available for borrow explorations such as hand augers, power augers, and test pits. Investigations are usually laid out on a grid pattern. The different borrow areas are typically labeled “A,” “B,” etc. Investigations for feasibility design normally are spaced at about 500-foot centers. Spacing is tightened to 250-foot centers or closer for final design. Closer spacing may be needed near the edges of the target materials.

Test pits or trenches are an essential component of borrow investigations. Longer trenches expose more of the borrow layers and should be considered in the exploration plans. It is essential that in initial designs, test pits are excavated and in-place density tests and compaction tests are run on the range of materials in the borrow area. By determining the in-place density and degree of compaction, the designer can determine the shrink or swell factors when the materials are used. The test pit or trench investigations should also note particle size and gradation, particle shape, coatings, and organic impurities. This data is also used to determine moisture requirements in construction. The pits expose the various strata in the borrow area. Decisions must be made about how to sample pits with different layering. The lead designers should be present during these investigations. Sometimes, a blend of certain layers is desired to obtain the desired engineering properties, and composite samples are taken (USBR 7000 [9]). Samples of representative soils shall be sent to the laboratory for advanced testing of shear strength, permeability, and compressibility. On figure 12.11-1, circled locations are examples where samples were sent for advanced testing.

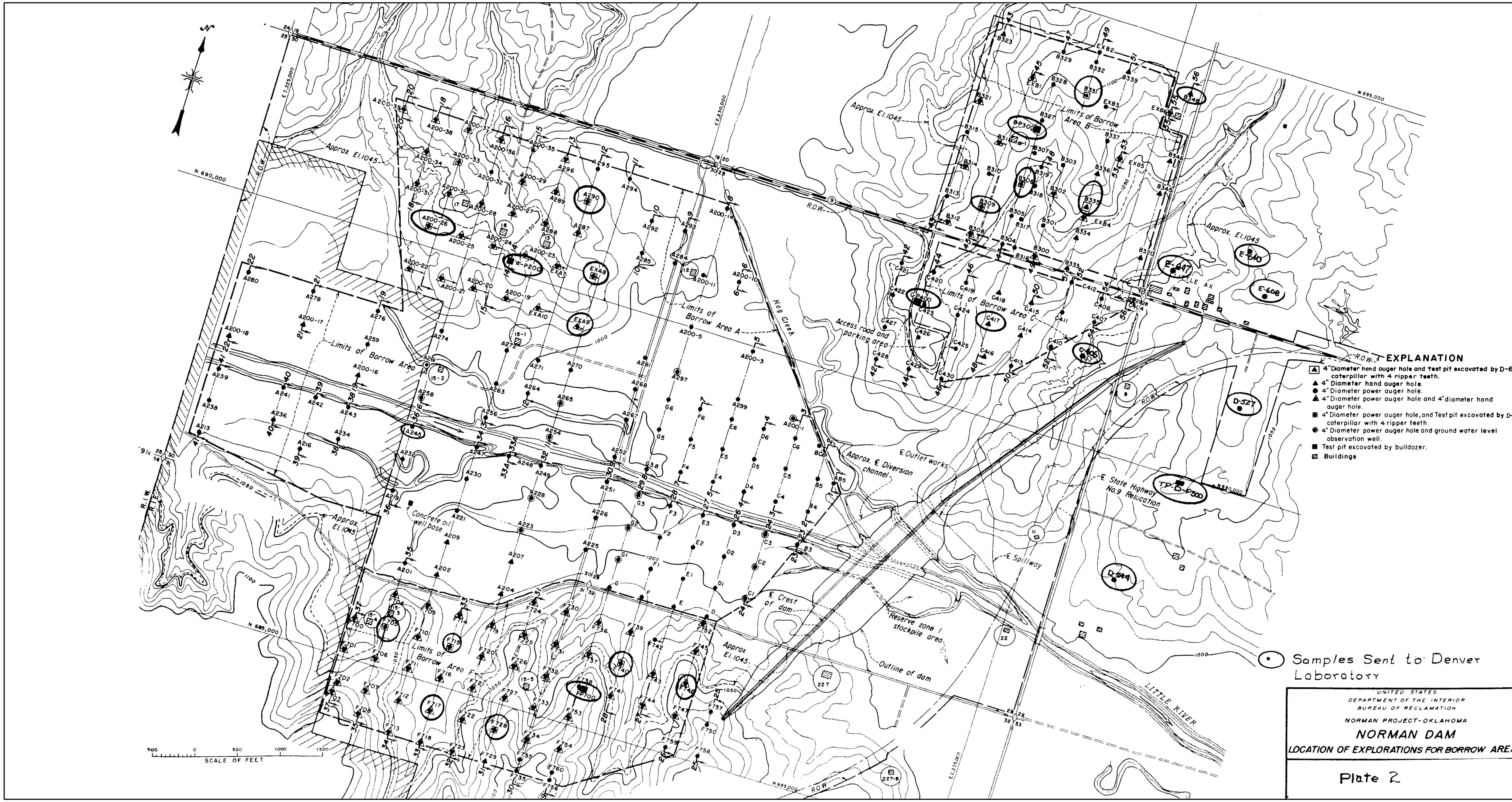


Figure 12.11-1. An example of a borrow exploration showing different borrow areas and explorations in a grid pattern. In some areas, closer spacing of explorations might be required.

Power augers provide a rapid and economical method of completing the grid to confirm that materials are available. Figure 12.11-1 shows how a combination of hand auger, power augers, and test pits are laid out. The layout may vary based on geologic conditions, and it is essential that a geologist be involved with the investigation plan.

For certain materials, such as decomposed granites or shale, the breakdown of soil particles needs to be evaluated, and compaction test sections are sometimes performed. The amount of oversize particles needs to be considered because the contractor may use this material to produce drainage materials. The amount of cobbles and boulders visually logged using the USCS is by volume, and cobbles are split into minus 5-inch and plus 5-inch sizes because plus 5-inch material is usually removed in compacted fill. The amount of boulders is estimated by volume. On critical projects where the amount of oversize particles must be known, large scale gradations can be performed, but at great expense. A crew with earth moving equipment is required to place 10,000 to 30,000 pounds of borrow soil through bar racks and sieves.

For wet borrow areas and borrow below the ground water level, observations wells should be installed to evaluate seasonal variations in moisture. Fine-grained borrow soil may be difficult to dry for optimum compaction conditions. In some cases, wet borrow soils may require installation of drainage trenches well in advance of construction. In some cases, dry, collapsible soils might require wetting in advance of construction.

There could be undesirable soils in the borrow area that may need to be wasted. Waste soil quantities should also be investigated completely.

12.12 Construction Materials Investigations

Frequently, adequate borrow materials are not available in the immediate vicinity of the earthwork structure. In such instances, it is often economical to obtain limited quantities of specific materials at a distance as close as possible from the site to minimize hauling costs. Such materials include impervious soils for cores, linings, or blankets; sand and gravel for concrete aggregate, filter blankets, drains, road surfacing, and, occasionally, materials for protection from erosion; and rock fragments for riprap or rockfill, filter blankets, or concrete aggregate [1].

12.12.1 Impervious Materials

There are situations where a need for a special source of impervious materials may be necessary for cores, blankets, or linings. When extensive permeable beds are found in foundations of dams or terminal, equalizing, or regulating reservoirs, it is a clear indicator to the investigator to locate a source of impervious material if other alternative measures are not cost effective. Most soils become impervious with the addition of 6- to 12-percent fines as reflected in the USCS system. For impervious core materials, its desirable to obtain higher fines content of around 25 percent. When used for water retaining embankments, it is desirable to locate soils with moderate plasticity because they are more resistant to internal erosion.

Hydraulic gradients through the blanket or lining will be high, so it is essential that the gradation prevent erosion and transport of fines from the blanket or lining into the pervious foundation materials and that a proper filter is provided beneath the blanket.

In dam design, it is seldom possible to reduce water losses appreciably with partial earth blankets, but seepage gradients can be reduced, in some cases, to the point where internal erosion is prevented. Materials for blankets in reservoirs do not need to be impervious; it is sufficient if their permeability is low compared to that of the foundation [1].

12.12.2 Pervious Materials

Durable sand and gravel are required for filters and drains, for bedding under riprap on earth dams, for drainage blankets under the downstream toes of earth dams, and for use as transition materials to prevent piping. It is unlikely that the design requirements can use natural deposits as filter, drains, or drainage blanket material: processing, including crushing, washing, and blending, is normally required. The economical haul distance from the site to areas in which investigations are made for locating a supply of pervious materials with special properties will vary depending on the need for such special material. The Materials Engineering and Research Laboratory has a database of quarries and can search the project area to help find sources. See reference [1] for a description of various applications requiring pervious materials with special properties.

12.12.3 Slope Protection

Rock fragments to protect against wave action or flowing water are designated as riprap. Material from rock sources should satisfy two main requirements. First, the rock source should produce rock fragments of suitable sizes, shapes, gradation, and weights according to required use. Second, the rock fragments should be tough and durable enough to withstand transportation and placement without breakdown and to withstand normal weathering, wave action, and other destructive forces associated with their particular placement or use. Samples of rock intended for use as riprap should be submitted for evaluation in sufficiently large quantities as appropriate for the maximum size anticipated. *Rock Manual* procedure USBR 6025 outlines Reclamations procedures for locating and testing riprap [35]. Test blasting and durability testing may be necessary to evaluate the source.

When rock is not locally available, there are substitutes available for riprap and rockfill blankets, such as soil-cement or concrete, asphaltic concrete, and steel for upstream slope protection, and sod cover for downstream slope protection.

12.13 Ground Water and Seepage Studies Investigations

12.13.1 Water Testing for Grouting

Water testing is necessary for evaluating seepage potential and for determining whether grouting is necessary or practical. Water testing for designing a grout program is often secondary to the main purpose of the water testing program, which is to determine permeabilities for seepage evaluation or control. The design of a program for water testing for grouting should consider:

- The type of structure to be built.
- The geologic conditions at the site and the variations between areas or reaches.
- The level of seepage control desired.
- Groutability and permeability are not necessarily related.
- Exploratory drill hole orientations introduce a significant bias into water test results.
- Water test calculation results can be very misleading.
- Different rock types, geologic structures, or in situ stresses have different jacking and hydrofracture potential and, therefore, different maximum acceptable water testing and grouting pressures.
- Rules of thumb are not good substitutes for using data and judgment in making decisions in grouting unless specifically developed for the site conditions.

Chapter 16 of the *Engineering Geology Field Manual* describes proper procedures, calculations, and equipment for conducting water testing for grouting. In addition, refer to the *Drainage Manual* [44] and the *Design Standards*.

12.13.2 Water Testing and Permeability

Most rock and soil contain numerous open spaces where water may be stored and through which water can move. Permeability, or hydraulic conductivity, is a measure of the ease of movement of fluid and gas through the open spaces and fractures. Water movement through soil and rock significantly impacts the ability to control water during construction. The movement of water through slopes must be known to understand the stability of slopes. Chapter 17 of the *Engineering Geology Field Manual* [6] describes proper procedures for conducting water testing for permeability.

12.13.2.1 Pressure Permeability Tests in Stable Rock

Permeability tests are routinely performed in rock, particularly by pressure or packer tests. The test water take is effectively controlled by fractures because the intact rock permeability is effectively zero in most cases. The water may be flowing into one or many fractures in the test interval, but the permeability calculation assumes laminar flow from an isotropic, homogenous medium. The length of the test interval is governed by the rock characteristics. Typically, the test interval may be 10 feet long, but the water can be going into one ¼-inch open fracture. Test intervals greater than 20 feet are inadvisable because, typically, there are a few fractures or a relatively small zone that controls the ground water flow in bedrock. The calculated permeability of the packer test interval may be a magnitude different from the actual rock mass permeability. The orientation of the drill hole relative to the fractures significantly affects the number of fractures intercepted by the hole and the perceived permeability. The pressure used for the water test should consider geologic structure because excess pressures can result in fracturing and apparently high permeabilities. Chapter 17 of the *Engineering Geology Field Manual* [6] describes proper procedures and equipment for conducting water testing for permeability in stable rock.

12.13.3 Aquifer Testing

Of the other tests described below in single boreholes, the pump-out aquifer test is considered the best method of determining the hydraulic conductivity of a geologic unit. These tests are often performed when construction de-watering is anticipated and conditions need to be accurately known. Reclamation's *Ground Water Manual* describes the test methods for the pump-out aquifer test. In the aquifer test, a central pump-out well is surrounded by observation wells located at differing spacings. The drawdown cone of depression around the pump well is allowed to stabilize under different pumping rates. From this test, one can determine transmissivity and storage coefficient in addition to formation permeability. Aquifer test software is typically used to analyze the test.

12.13.3.1 Gravity Permeability Tests

Gravity permeability tests are used primarily in unconsolidated or unstable materials. Gravity tests can only be run in vertical or near-vertical holes because of potential for caving or sloughing in the hole. A normal test section length is 5 feet. If a material is stable, stands without caving or sloughing, and is relatively uniform, sections up to 10 feet long may be tested. Shorter test sections may be used if the length of the water column in the test section is at least five times the diameter of the hole. Chapter 17 of the *Engineering Geology Field Manual* [6] describes proper procedures and equipment for conducting gravity permeability tests. Four procedures are described.

12.13.3.2 Falling Head Tests

Falling head tests are used primarily in open holes in consolidated rock. Falling head tests use inflatable packers identical to those used for pressure testing and can be used as an alternate method if the pressure transducer or other instrumentation fails. Chapter 17 of the *Engineering Geology Field Manual* [6] describes proper procedures for conducting falling head tests for permeability.

12.13.3.3 Slug Tests

Slug tests are performed by rapidly changing water levels in a borehole. The rapid change is induced by adding or removing small quantities of water, air, or an object that displaces the ground water. Slug tests are typically performed in areas where access or budget is limited or the extraction or addition of water has a potential impact to the surrounding area. Slug tests are appropriate where the aquifer will not yield enough water to conduct an aquifer test or the introduction of water could change or impact the water quality. Chapter 17 of the *Engineering Geology Field Manual* [6] describes proper procedures for conducting slug tests for permeability.

12.13.3.4 Piezometer Test

The piezometer test measures the horizontal permeability of individual soil layers below a water surface. This test may apply to large diameter direct push technology, to any depth that an open hole can be maintained. This test is particularly good for determining which layer below the capillary zone is an effective barrier. Chapter 17 of the *Engineering Geology Field Manual* [6] describes proper procedures and equipment for conducting piezometer testing for permeability.

12.14 In Situ Testing

In situ tests are often the best means for determining the engineering properties of subsurface materials and, in some cases, may be the only way to obtain meaningful results. In situ rock tests are performed to determine shear strength, in situ stresses, and deformation properties of a jointed rock mass. Critically weak partings, shears, or rock units within the rock mass and residual stresses along discontinuities may also be determined by in situ tests.

12.14.1 Field Tests for Engineering Properties

In situ field tests that are used to determine shear strength are briefly described below.

12.14.1.1 Standard Penetration Test

The SPT is useful for a preliminary appraisal of a site. The N-value obtained from SPT blow counts is useful for pile design and, in cohesive soils, can be used to determine where undisturbed samples should be obtained. The N-value can also be used to estimate bearing capacity and unconfined compressive strength of soils. N-values corrected for load of overlying material have become a valuable means of evaluating the liquefaction potential of foundation materials under earthquake loadings. Designation USBR 7015 of reference [9] and reference [26] describes proper procedures for conducting penetration resistance testing and sampling of soil. Figure 12.14.1.1-1 shows a typical SPT sample barrel.

Figure 12.14.1.1-1. View of a split-spoon SPT sample barrel.

The penetration resistance record in sands can be used to: (1) estimate in situ relative density, (2) proportion footings, and (3) assess liquefaction potential. When the test is to be used for assessing liquefaction potential, extreme attention to detail is required. Detailed procedures for liquefaction investigations are described in ASTM D 6066 [30]. This practice restricts the drilling methods that can be used and requires that the drill rod energy of the hammer system be known. If gravel is encountered, the number of blows per each 0.1 foot of penetration should be recorded to verify the test or make adjustments when interpreting data if necessary. In some cases, the amount of penetration per blow is recorded. In these instances, supplemental guidelines may be issued. In fine-grained soils, the penetration resistance can be used to qualitatively evaluate consistency and undrained shear strength.

12.14.1.2 Becker Penetration Test

The BPT is used for liquefaction resistance evaluations for gravelly soils and has become synonymous to the SPT for sandy soils. When first proposed, the variable energy of the drill was adjusted using bounce chamber pressures [12].

Now, pile driving analyzers are used for energy corrections. Adjusted BPT blow counts are converted to equivalent SPT blow counts using empirical BPT-SPT correlations. The equivalent SPT blow counts should then be normalized for the effects of overburden pressure prior to correlating the equivalent blow count data to the desired engineering parameters. Reclamation recently performed a review of the Becker penetration and other liquefaction evaluation methods, and detailed information on the Becker test is included in reference [31]. Additional information can be found in reference [43].

12.14.1.3 Cone Penetrometer Test

The CPT can provide economical, detailed information on soil stratigraphy, and with proper correlation and verification, preliminary estimates of geotechnical properties can be made. The test is limited to finer-grained soils and cannot be conducted in coarse, gravelly soils or lithified materials. Based on the soil type, as determined by the CPT or adjacent boring, the undrained strength can be estimated for clays, and the relative density can be estimated for sands. The friction angle can also be estimated in clean sands but is not as accurate in dirty sands. New software has the ability to estimate modulus of varying types. Continuous electrical readout systems that can obtain pore pressure measurements have helped promote understanding of the data. (The pore pressures do not represent the actual pore pressure but, rather, a dynamic pore pressure associated with cone penetration into the material.) ASTM procedure D 5778 of reference [32] describes proper procedures for testing.

A CPT rig and CPT probe are shown in figures 12.14.1.3-1 and 12.14.1.3-2, respectively.

Figure 12.14.1.3-1 Forty-ton CPT rig used by Reclamation.

Figure 12.14.1.3-2 CPT probe being advanced through a "starter" hole.

12.14.1.4 Field Vane Shear Tests

Field vane shear tests performed in boreholes can provide useful data in soft, sensitive clays that are difficult to sample (figure 12.14.1.4-1).

Figure 12.14.1.4-1. A vane shear test in progress using a drill rig to provide torque. Many sizes of vanes are available as shown in second photograph.

However, test values are sometimes too high or too low and require adjustment by empirical procedures such as described in ASTM procedure 2573. These tests are often complemented with CPT and laboratory tests on undisturbed samples. Reclamation uses a Nilcon vane shear apparatus that is used in hollow-stem auger drill holes and no longer uses the older equipment shown in the *Earth Manual*. ASTM procedure D 2573 of reference [33] describes proper procedures for performing field vane shear testing.

12.14.1.5 Direct Shear Tests

In situ direct shear tests are expensive and are performed only when doubt exists about available shear strength data and where thin, soft, continuous layers exist within strong adjacent materials. The tests can be performed on soils or on rock core samples and sometimes are performed for sliding friction of concrete on rock. The direct shear test is performed to measure peak and residual strength (soil) or sliding friction (rock) as a function of stress normal to the shear plane. Reclamation has special rock direct shear machines that are used to test rock and its discontinuities. Test values are usually used in limiting equilibrium analysis of slope stability or for stability analysis of foundations for large structures such as dams. Designation USBR 5725 of reference [9] describes proper procedures for performing direct shear testing of soils.

For rock, there are portable direct shear testing devices for rock cores and borehole shear tests that can be performed in the field. The portable direct shear device requires some time consuming preparation of the rock core by encapsulating the specimen in the shear boxes. This can be done at the field site, but often the laboratory tests can be performed for the same effort. The borehole shear device is useful for testing poor quality rock, which is difficult to recover when cored. Procedures for these tests are given in Reclamation's *Rock Manual* located on Reclamation's Intranet site.

12.14.1.6 Point-Load Strength Test

Rock strength is an important property, and a suitable strength-index test is required. The uniaxial (unconfined) compression test has been widely used for rock strength classification but requires machined specimens and, therefore, is an expensive technique essentially confined to the laboratory.

The point-load test is conducted in the field on unprepared rock specimens using simple portable equipment (figure 12.14.1.6-1). Essentially, the test involves compressing a piece of rock between two points. The point-load test has a number of variations such as the diametral test, the axial test, and the irregular lump test. Reclamation experience indicates that the results may vary with geologic rock type, as well as condition of the sample. Therefore, a site-specific correlation should be developed and the variability of the results should be evaluated prior to use.

12.14.1.7 Schmidt Hammer Test

A Schmidt hammer, also known as a rebound hammer, is a device to measure the elastic properties or strength of concrete or rock (figure 12.14.1.7-1). The hammer measures the rebound of a spring-loaded mass impacting against the surface of the sample. The rebound value can be used to determine compressive strength. The rebound reading can be affected by the orientation of the hammer, local variation in the sample, and water content of the sample. Therefore, prior to testing, the Schmidt hammer should be calibrated using a calibration test anvil supplied by the manufacturer for that purpose. This method of testing is classed as indirect because it does not give a direct measurement of the strength of the material. It simply gives an indication based on surface properties and is only suitable for making comparisons between samples.

This test method for testing rock is governed by ASTM procedure D5873 [34].

Figure 12.14.1.6-1. Point-load test apparatus.

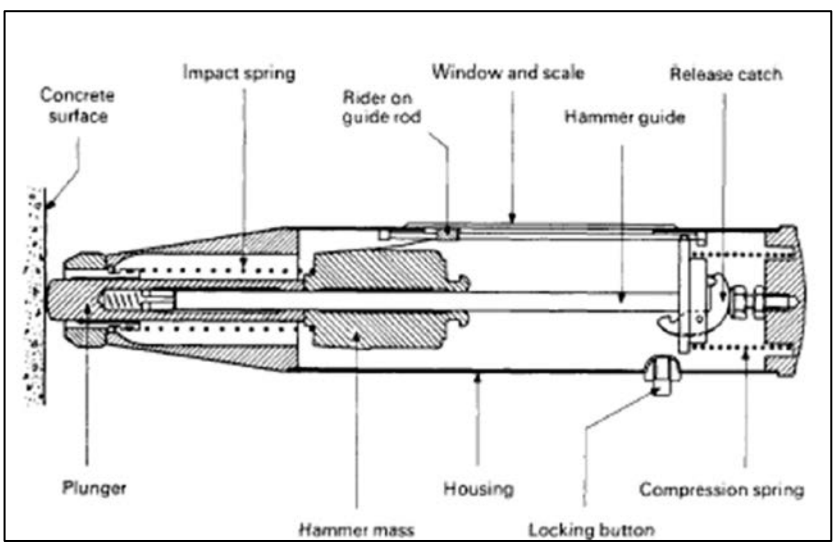


Figure 12.14.1.7-1 Schematic of Schmidt hammer used to estimate strength of materials in the field.

12.14.1.8 Penetrometer Test

The pocket penetrometer instrument is used to estimate approximate unconfined compressive strength and to estimate shear strength of soil (figure 12.14.1.8-1). The handy and convenient instrument is commonly used on split spoon and thin walled tube samples to evaluate consistency and approximate unconfined compressive strength of saturated cohesive soils. They may also be used for the same purpose in test pits.

Figure 12.14.1.8-1. View of pocket penetrometer used to estimate soil strengths in the field.

12.14.1.9 TORVANE Test

The TORVANE is a hand-held vane shear device for rapid determination of shear strength in cohesive soils either in the laboratory or the field (figure 12.14.1.9-1). The TORVANE allows shear strength to be measured in the sides of test pits, trenches, or excavations. It may also be used on the ends of thin wall or split spoon samples and soil chunks removed from test pits, etc. The TORVANE permits the rapid determination of a large number of strength values with different orientation of failure planes. It is simple to use, and sample trimming is eliminated. All that is required is a reasonably flat sample surface 1 inch in diameter. It should be used only for fully saturated cohesive soils whose undrained strength is independent of normal pressure. The stress range permits it to be used for clays varying in consistency from very soft to stiff.

Figure 12.14.1.9-1. View of TORVANE test shear device.

12.14.2 Tests to Determine In Situ Stress

The results of in situ tests to determine stress in rock are used in finite element analyses, for estimating loading on tunnels, vertical pressure shafts, and for determining rock burst susceptibility in excavations, as well as for identifying regional active and residual stresses. In situ testing is the most reliable method for obtaining the magnitude and direction of such stresses. The three most common methods for determining in situ stresses in rock are the "Overcoring Method," the "Flatjack Method," and the "Hydrofracture Method." Proper application and procedures for performing these methods are described in Reclamation's *Rock Manual* [35].

Determinations of in situ stresses in soils are more difficult. There has only been limited success in measurement of in situ stress. The Iowa Stepped Blade test can be used in fine-grained soils.

12.14.3 In Situ Tests to Determine Deformation

Deformation characteristics of subsurface materials are of major importance in dynamic and seismic analyses for dams and other large structures, and static design of tunnels. Geotechnical investigations for such purposes should be planned jointly by engineering geologists and geotechnical and structural engineers. Deformation properties are normally expressed in terms of three interdependent parameters. These are: Young's modulus, shear modulus, and Poisson's ratio. These parameters are valid only for materials that are linear, elastic, homogenous, and isotropic. In spite of this limitation, these parameters are often used to describe the deformation properties of soil and rock. Large-scale tests are used because they reduce the effect of nonhomogeneity. For a description of the in situ tests used to determine deformation characteristics, see references [1] and [5].

In recent years, the pressuremeter or dilatometer test has been used more widely in determining the engineering properties of soil or rock in place. The engineering properties include shear strength, stress conditions, and mass deformability [1, 5].

12.14.3.1 Plate Bearing Tests

Plate bearing tests can be made on soil or soft rock. They are used to determine subgrade moduli and, occasionally, to determine strength. The usual procedure is to jack-load a 12- or 30-inch-diameter plate against a reaction to twice the design load and measure the deflection under each loading increment. Because of their cost, such tests are normally performed during advanced design studies or during construction.

12.14.4 Determination of Dynamic Modulus by Geophysical Methods

Geophysical methods, both downhole and surface, may be used to determine in-place moduli of rock and soil. The compressional wave velocity is mathematically combined with the material's mass density to estimate a dynamic Young's modulus, and the shear wave velocity is similarly used to estimate the dynamic shear modulus. However, because the strains are so small and loading is transitory during these seismic tests, the resulting modulus values are nearly always too high for other usage. The seismic method of measuring soil and rock modulus should not be used in cases where a reliable static modulus value can be obtained. Even where the dynamic modulus is to be used for earthquake analyses, the modulus derived from seismic methods is too high. The moduli and damping characteristics of soil and rock are strain dependent, and the strains imposed on the rock during seismic testing are several orders of magnitude lower than those imposed by a significant earthquake. Generally, as strain levels increase, shear modulus and Young's modulus decrease and damping increases. Consideration of these factors is necessary when performing earthquake analyses. See reference [6].

12.15 Laboratory Testing

Laboratory tests for basic engineering properties of strength, compressibility, and permeability are almost always performed in embankment dam investigations. Samples and testing requirements are identified by the investigation team in the FERs. Separate design standards such as those on stability, seepage, riprap, etc., describe advanced laboratory tests that should and can be performed.

12.16 Backfilling of Boreholes and Exploratory Excavations

Except where the hole is being preserved for future use, all boreholes and exploratory excavations will be backfilled. Backfilling helps to prevent and minimize safety hazards for personnel and animals, prevents ground water contamination of aquifers, minimizes seepage problems of dams and levees, and minimizes adverse environmental impacts. Holes preserved for water level readings, the installation of instrumentation, borehole examination, or downhole geophysical work should be backfilled when no longer needed. Completion methods of borehole with instruments are described in *Design Standards.*

Hole abandonment is often not given the consideration it deserves, and many times it is not well documented. Completing a borehole by backfilling with drill cuttings is generally not acceptable. There are a variety of acceptable methods to complete a borehole, including high solids bentonite grout, neat cement grout, and bentonite pellets or chips. Hole completion methods may be dictated by environmental permit requirements.

Recommended borehole completion documentation should include intervals of various backfilling materials, calculated volume of material necessary to fill each interval, and actual volume of material required to fill each interval. Detailed records of borehole completion are vital and, as in the case of backfill material volumes significantly higher or lower than calculated, may be indicative of conditions significantly different than anticipated. Recommended *Guidelines for Sealing Geotechnical Exploratory Holes*, Report 378, is a good source for borehole backfill guidelines [27]. Additional guidelines and cautions can be found in references [28] and [29].

As a minimum, borings that are preserved for future use should be protected with a short section of surface casing, capped, locked, and identified. Test pits, trenches, and shafts should be provided with suitable covers or barricades until they are backfilled. Where conditions permit, exploratory tunnels may be sealed in lieu of backfilling. Refer to appendix F, chapter F-14, in reference [5].

12.17 Care, Retention, and Disposal of Drill Core and Samples

The procedures and criteria outlined in chapter 24 of reference [6] will be used to determine care, retention, and disposal of drill core and samples secured in explorations during investigations for design and construction of Reclamation structures. These standards are intended to minimize storage costs, meet minimum technical requirements, and avoid unnecessarily long storage periods.

When samples taken in sleeves or containers, or undisturbed hand-cut samples, are specifically intended for laboratory examination or testing to supply design data, such samples should be taken, prepared, cared for, and handled in accordance with the *Earth Manual* [1] and *Rock Manual* [35]. Samples should be shipped immediately to an appropriate laboratory to avoid deterioration, change in physical properties, and adverse effects on test results. Chapter 23 of the *Engineering Geology Field Manual* [6] and Reclamation's *Rock Manual* [35], located on Reclamation's Intranet site, describe proper procedures for protecting and shipping samples. An appropriate transmittal letter shall be sent along with sample shipments, logs, sample data sheets, or other pertinent information.

12.18 Test Quarries, Test Fills, and Trial Embankments

The USACE *Engineering Manual* [36] is an excellent reference for planning and conducting test quarries and test fills. These large scale tests are expensive and must be planned and executed carefully.

12.18.1 Test Quarries

Quarrying tests are usually conducted in conjunction with test fill programs and in areas where large quantities of rock material will be needed from undeveloped sources. Before a test quarry program is undertaken, a careful geologic study should be made of the test quarry site and should include: (1) field reconnaissance and mapping of all discontinuities; (2) examination of boring logs, rock cores, and borehole survey results; (3) consideration of regional stress fields and site-specific stress conditions that could affect stress relief during quarrying operations; (4) development of geologic sections and profiles; and (5) consideration of all other factors that may control size, quantity, and quality of blasted rock.

12.18.2 Test Fills and Trial Embankments

Test fills are usually recommended where unusual soils or rockfill materials are to be compacted or if newly developed and unproven compaction equipment is to be employed and where material breakdown is a concern. Rock test fills are most frequently required simply to determine optimum placement and compaction operations. Test fill operations must be representative with regard to prototype materials and placement and compaction procedures.

Trial embankments should be constructed to resolve uncertainties about the probable behavior of complex subsurface conditions or of poor quality embankment materials.

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Appendix A

Example of a Field Exploration Request

DATE	PEER REVIEWER(S)	CODE
6-18-08	Gary Tuttle (signature) Gary Tuttle (printed name)	86-68320

PEER REVIEW NOT REQUIRED

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DATE		
6/18/08	Weghorst	84440

Classification
Project
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Folder I.D.

86-68320
PRJ-1.10

86-68410

MEMORANDUM

To: Regional Director, Boise, Idaho
Attention: PN-3251 (Wolf)

Through: Chief, Dam Safety Office *Karen Weghorst*
Attention: 84-44000 (Weghorst)

From: Gary Russell, Geologist *[signature]*

Subject: Field Exploration Request – Scoggins Dam – Tualatin Project (Geological Exploration)

Attached is a Field Exploration Request (FER) to collect data at Scoggins Dam, Tualatin Project, Oregon. These investigations will be performed on the dam crest, downstream face and toe area to evaluate the characteristics of the embankment and foundation materials, and better define the site's response to large earthquakes. The geologic and geophysical investigations are required to satisfy Safety of Dams Recommendation 2008-SOD-A, of the Scoggins Dam Issue Evaluation. Data obtained from this field program and from past geologic investigations at Scoggins Dam will be used in the analyses of dynamic stability and will be used to determine whether the foundation constitutes a risk that requires corrective action.

Field explorations include cone penetrometer tests, crosshole shear wave tests, a surface seismic refraction survey, vane shear tests, standard penetration tests, undisturbed sampling of embankment and foundation soils, and core sampling of the spillway concrete. Laboratory testing of the soils and concrete will also be conducted by the Technical Service Center (TSC), Pacific Northwest (PN) Region, and contract laboratories. Draft and final reports of exploration activities and testing results will be prepared by the PN Regional Office and TSC groups upon completion of the various investigations.

Depending on the results of these investigations, Becker penetration testing of the coarse-grained, basal alluvial layer may eventually be required. A Becker testing program is currently not included in this FER. If needed, this work would be accomplished under contract.

Estimated costs for the PN Region total $1,094,000. This cost estimate includes drilling costs, laboratory testing costs, field expenses and supplies, office expenses, consultant services (for surveys of hole locations), contractor services (for access ramp construction and repair, and LiDAR data acquisition), vehicle costs, and salaries for PN-3600 (Geology, Exploration and Instrumentation) field and office personnel. Preparation of the geologic field investigation report, and participation in progress meetings with the TSC are included in this cost estimate.

Estimated costs for the TSC total $400,000. This cost estimate includes all field and office expenses associated with the following investigations and activities:

- Cone Petrometer Tests
- Vane Shear Test Field Training
- Geophysical Crosshole Shear Wave Tests
- Surface Seismic Refraction Survey
- Concrete Coring of the Spillway Floor and Walls
- Laboratory Tests of Undisturbed Soil Samples
- Laboratory Tests of Concrete Core Samples
- Preparation of Investigation and Testing Reports

The TSC estimate also includes 86-68312 and 86-68320 costs for preparation of the FER, support during the field investigations, site visits, and participation in progress meetings with field personnel and PN Regional Office.

Draft copies of this FER were sent to and discussed with Dick Link, PN Regional Geologist, and with A.J. Mitchell, PN Regional Drill Foreman. If you have any questions or comments on this program, please contact me at 303-445-3146, or Bill Engemoen at 303-445-2960.

Attachment

cc: 94-46000 (Brynda)
(w/o att)

84-44000 (Dinneen, Weghorst), 86-68311 (Files), 86-68312 (Engemoen), 86-68320 (Russell), 86-68180 (Strauss), 86-68110 (Koltuniuk), 86-68410 (DSDaMS), 84-21300, (Archives) (Originals) PN-3600 (Link), BFO-3200 (Healy) BFO-3230 (Stelma)
(w/att to each)

WBR:GRussell:kw:06/18/2008:303-445-3146
c:KWasik:RussellFinalFERCoverLtr2

TSC FIELD EXPLORATION REQUEST

REGION: Pacific Northwest
PROJECT: Tualatin
FEATURE: **Scoggins Dam**
DATE: June 2008

PURPOSE: Provide Geotechnical Data for Dynamic Analysis
TSC COORDINATOR: Bill Engemoen, 303-445-2960
CONTACT: Gary Russell, 303-445-3146
DATA SUBMITTAL DATE: See Items H through K

TEAM MEMBERS
B. Engemoen R. Koltuniuk
T. Strauss G. Russell
R. Link D. Stelma
A.J. Mitchell J. Wright
J. Farrar

Description of Dam Safety Program Decisions, Scoggins Dam: A Dam Safety Advisory Team (DSAT) review of the Decision Document "Evaluation of Seismic Risks at Scoggins Dam" was conducted on March 6, 2008. The Scoggins Dam Issue Evaluation includes several new Safety of Dams (SOD) recommendations which were made as a result of the high estimated mean seismic risks. Recommendation 2008-SOD-A states: "Develop and perform a field exploration program for Scoggins Dam that will obtain information that will better define the earthquake loading and the site's response to large earthquakes."

Field Exploration Program: This field exploration request (FER) describes the specific geologic and geophysical investigations which are required to satisfy recommendation 2008-SOD-A. It will also provide the basis for estimating exploration costs. Data obtained from this field program and from past geologic investigations at Scoggins Dam will be used in the analyses of dynamic stability.

Reports will be prepared which summarize the procedures, results and findings from the investigations described below. These reports (Items H through K) should include the applicable geologic drill hole logs, field data, drawings, photos, test results and conclusions.

Item	Description	Location	Method and Size	Depth	Sampling	Instrumentation and Testing	Remarks
A	Data Search						Research and assemble existing geologic and geotechnical data pertaining to this structure and foundation.
B	18-22 Cone Penetrometer Tests (CPT) and 5 Seismic Cone Penetrometer Tests (SCPT)	Approximate CPT and SCPT locations are identified on Figures 1 and 2. Refer to 2/ in the Notes for details of specific hole locations	The tests will be performed by TSC personnel using a Reclamation-owned truck-mounted CPT rig. The three locations on the lower face may require pre-drilling from the ground surface to a depth of about	**Toe and Downstream Area**: Test from the ground surface to the top of bedrock (approximately 40 feet deep), unless refusal is met in the coarse grained basal alluvium.			Cone penetrometer tests (CPT and SCPT) should be the first explorations performed at the site; and the CPT's along the toe should be done before those in the downstream area. The data and results from these investigations will give an indication of foundation geologic conditions, lateral continuity and properties which may help with the selection specific testing and sampling locations in the other investigation holes. CPT and SCPT tests are required in the foundation soils only, and not in the embankment materials. The CPT tests are performed using a cylindrical penetrometer with a conical tip (cone) penetrating the ground at a constant rate. During the penetration, continuous measurements are made of the resistance to penetration of the cone and the friction of the outer surface of a sleeve.

Item	Description	Location	Method and Size	Depth	Sampling	Instrumentation and Testing	Remarks
			30 feet, in order to penetrate the coarser Zone 3 embankment materials. Each pre-drilled interval will be backfilled with sand prior to SCPT testing.	**Lower Face**: Test the foundation soils from about 30 feet to 60 feet deep (the top of bedrock) unless refusal is met in the coarse grained basal alluvium.			The Seismic Cone Penetrometer Test (SCPT) is a technique to determine in-situ down-hole shear wave velocities. The seismic test method consists of measuring the travel times of body waves propagating between a wave source on the ground surface and an array of geophones in an in-situ seismic cone penetrometer. The seismic wave velocities give an indication of shear modulus for seismic response analysis, and allow correlation of seismic profiling data with geotechnical borehole and CPT results. Following the completion of the cone penetrometer tests and verification of the data, all holes should be backfilled with granular bentonite or cement, in accordance with Reclamation and State requirements.
C	12 Boreholes (four triplets) for Geophysical Crosshole Shear Wave Testing	Triplet locations are identified on Figures 1 and 2 at the following locations: **Dam Crest:** One triplet on the <u>upstream</u> edge of the crest, at Station 14+87.5 Station 15+00 Station 15+12.5 Note: Depending on the results of the tests along the toe, this triplet may be relocated to about station 7+00 on the crest.	A drilling method which minimizes hole deviation should be used. Mud Rotary, driving 6-inch I.D. casing has been suggested by PN Drill Foreman. The dam crest triplet holes will be drilled through the Zone 1 core of the embankment. The casing must be advanced ahead of the drill bit, and pressures kept to a minimum in order to prevent hydraulic	All triplet holes should extend 20 feet into bedrock, maintaining a minimum 6-inch diameter. Approximate hole depths are as follows: Dam Crest: 165 feet Upper Face: 140 feet D/S Toe: 60 feet	Perform undisturbed sampling in the first hole drilled at each triplet location so that if sampling problems arise, another hole is available for sampling. Obtain undisturbed samples according to procedures in the Notes under **3**/. The bedrock (sandstone) may be	**Geophysical Crosshole Shearwave Testing**: Perform the shear wave surveys along the entire length of the triplet holes. **Laboratory Soil Testing**: Follow the procedures outlined in the Notes below in **4/.** **Vane Shear Testing (VST):** Perform VST tests in one of the Dam Crest Triplet boreholes and one of the Upper Face Triplet boreholes. VST tests will be	Refer to Attachment 1 for shear wave hole installation details. Each borehole should be drilled so that hole deviation is minimized and the spacing between the three holes (of each triplet) remains fairly consistent from top to bottom. A borehole deviation survey will be conducted in each boring to determine the horizontal distances at depth between borings. Thorough notes of drilling conditions are important **8**/. Following the completion and verification of the geophysical surveys and other tests, all triplet holes should be completed by backfilling the holes with bentonite pellets or cement, in accordance with Reclamation and State requirements.

Item	Description	Location	Method and Size	Depth	Sampling	Instrumentation and Testing	Remarks
		Upper Face: One triplet about 75 feet downstream of crest centerline at Station 14+87.5 Station 15+00 Station 15+12.5 **Toe:** Two triplets, each about 400 feet downstream of crest centerline at: Station 14+90 Station 15+00 Station 15+10 Station 6+90 Station 7+00 Station 7+10	fracturing of the core **1/**. All triplet holes must have a minimum diameter of 6 inches to allow enough annular space for grouting of the 4.5-inch O.D. PVC shear wave casing.		weathered and poorly cemented, making it difficult to distinguish from the overlying soils based on drilling conditions. Verify the top of bedrock with a sample. Core samples of bedrock for the entire 20-foot interval are optional.	done only in the fine-grained cohesive foundation soils. Follow the procedures outlined in the Notes below in **5/**. **Standard Penetration Test (SPT):** Perform SPT tests in one of the boreholes at each triplet location. SPT tests will be done only in the cohesionless coarser-grained basal soil unit. Follow the procedures outlined in the Notes below in **6/**.	
D	1 Drill Hole For Undisturbed Sampling of Foundation Soils.	**Lower Face**: About 270 feet downstream of crest centerline at Station 14+90. See Figures 1 and 2. Depending on the results of the CPT tests, this borehole may be relocated to about station 7+00, 270 feet downstream.	Fluid Rotary, driving 6-inch I.D. casing has been suggested by PN Drill Foreman.	To the top of bedrock, approximately 55 feet deep.	Obtain undisturbed samples according to the procedures outlined below in the Notes under **3/**.	**Laboratory Soil Testing**: Follow the procedures outlined in the Notes below in **4/**.	Undisturbed sampling is required in the foundation soils only, and not in the embankment materials. Thorough notes of drilling conditions are important **8/**. Water levels should be measured in the drill holes at the beginning and end of each shift. Verify the top of bedrock with a cored sample (if possible). Following the completion of drilling and sampling, backfill the holes with bentonite pellets or cement, in accordance with Reclamation and State requirements.

Item	Description	Location	Method and Size	Depth	Sampling	Instrumentation and Testing	Remarks
E	6 Drill Holes For Vane Shear Testing (VST) and Standard Penetration Testing (SPT).	See Figures 1 and 2. The locations listed here are approximate. The final locations may be adjusted based on the results of the ECPT tests. Each VST hole should be located near an ECPT hole and/or a crosshole triplet. **Lower Face**: About 270 feet downstream of crest centerline at: Station 7+10 Station 15+10 Station 20+10 **D/S Toe:** About 400 feet downstream of crest centerline at: Station 6+80 Station 14+80 Station 20+10	Fluid Rotary, driving 6-inch I.D. casing, or 4.25-inch I.D. Hollow Stem Auger (HSA). Use of the HSA on the lower face will depend on the maximum size rock fragments in the Zone 3 embankment.	Lower Face Holes: To the top of bedrock, approximately 55 feet deep. D/S Toe Holes: To the top of bedrock, approximately 40 feet deep.	Recover over-core samples from the VST intervals. If the HSA system is used, over-core samples will be recovered in the auger split barrel sampler. Recover SPT samples from the basal unit.	**VST Testing:** Testing will likely be done using a Nilcon M-1000 Vane Borer. The vane size is 4 inches long by 2 inches diameter. Refer to <u>5</u>/ in the Notes below. Perform laboratory testing of over-core samples to obtain standard soils index properties (see Note <u>4</u>/). **SPT Testing:** Testing will be done only in the cohesionless coarser-grained basal soil unit (if encountered). Follow the procedures outlined in the Notes below in **<u>6</u>/.** Perform laboratory testing of SPT samples to obtain standard soils index properties (see Note <u>4</u>/).	VST tests should be performed only in the fine-grained cohesive foundation soils. SPT testing will be done only in the cohesionless coarser-grained basal soil materials. Thorough notes of drilling conditions are important **<u>8</u>/**. Water levels should be measured in the drill holes at the beginning and end of each shift. Verify the top of bedrock with a short sample (if possible). Following the completion of drilling, testing and sampling, backfill the holes with bentonite pellets or cement, in accordance with Reclamation and State requirements.

Item	Description	Location	Method and Size	Depth	Sampling	Instrumentation and Testing	Remarks
F	Surface Seismic Refraction Survey	Along the downstream toe. See Figure 1.	The survey line will be approximately 1500 feet in length. Shot holes will be spaced along the line on about 60 foot centers.	Shot holes will have an average depth of about five feet.			About 25 shot holes (on about 60 centers) will be drilled along the survey alignment. The TSC Geophysics Group will perform the field work to obtain the seismic refraction data. However, the blasting will likely be contracted to a licensed blaster, who will also contact the necessary authorities and obtain any required permits.
G	10 Spillway Core Holes	Four core holes in the spillway walls, two in the pier, and four in the spillway floor. Specific locations will be determined in the field.	Core samples of the concrete will be obtained using standard masonry drilling equipment. Each hole will be approximately 6-inches in diameter.	Hole depths are expected to be less than 3 feet.	Concrete core samples, 6-inch diameter.	Laboratory testing of concrete core; see Remarks and **10/**.	Laboratory testing should be performed on each concrete core sample; and include a cylinder breaking test for compressive strength, and a petrographic examination. The TSC Materials Engineering and Research Laboratory (86-68180) will perform the drilling to obtain the concrete core samples, prepare and protect the samples, transport the samples, and perform the laboratory testing.
H	Geologic Field Investigation Report						Prepare a report of exploration activities. Enter all drill hole data into a gINT database geologic log structure. Develop geologic plan drawing(s) with locations of explorations; and develop geologic cross section drawing(s) to illustrate subsurface conditions and relationships. Include in the report all testing field forms which show the VST and SPT data. Include photographs and any additional data (including laboratory data) which may be useful for analyses. Provide two copies of the draft report within 60 days after completion of investigations. Send to 86-68312 (Engemoen) and 86-68320 (Russell).
I	Cone Penetrometer Testing Report						Prepared by TSC Engineering Geology Group. This report will summarize the procedures, results, interpretations and conclusions from the cone penetrometer testing. Provide two copies of the draft report within 30 days after completion of investigations. Send to 86-68312 (Engemoen) and 86-68320 (Russell).

Item	Description	Location	Method and Size	Depth	Sampling	Instrumentation and Testing	Remarks
J	Geophysical Crosshole Shear Wave Testing Report						Prepared by TSC Geophysics Group. This report will summarize the procedures, results, interpretations and conclusions from the geophysical crosshole shear wave testing. Provide two copies of the draft report within 30 days after completion of investigations. Send to 86-68312 (Engemoen) and 86-68320 (Russell).
K	Report of Laboratory Testing Results						Laboratory testing performed in the TSC labs and the results of testing performed by contract labs should be included in summary reports.

NOTES

1/ Drilling will be done in the Zone 1 core and downstream shells of the embankment. Extreme caution should be implemented to avoid any possibility of hydraulic fracturing of the embankment. Required procedures for drilling in embankment dams should be followed at all times.

2/ Cone Penetrometer Tests (CPT) Seismic Cone Penetrometer Tests (SCPT)

Perform CPT and SCPT tests in the following locations:

Lower Face:

3 SCPT tests will be on the lower face adjacent to VST holes, about 270 feet downstream of crest centerline at Stations 7+00, 15+00 and 20+00.

Toe:

13 CPT tests and 2 SCPT tests will be along the downstream toe, about 400 feet downstream of crest centerline. These should be spaced on about 100 foot centers. It is important to locate the two SCPT tests at about Stations 7+20 and 15+20, near the toe crosshole triplets.

Downstream Area:

5-9 CPT tests will be completed about 150 feet downstream of the toe CPT holes. Spacing of downstream area CPT holes will depend on the results of the tests along the toe. If the results indicate variable foundation conditions, then 10 CPT's should be completed on 100 foot centers. If the foundation materials are generally unvarying, then 5 CPT's should be completed on 200 foot centers.

3/ Undisturbed Sampling

Obtain undisturbed samples of the fine grained (clayey and silty) foundation soils according to USBR Procedure 7105 for performing undisturbed soil sampling by mechanical drilling methods. Measure tube densities in the field soon after the samples are retrieved from the hole. Samples will be recovered in 2.5-foot long, 5-inch diameter thin-walled steel tubes. Sampling of the underlying coarser (sandy and gravelly) foundation materials are encountered should be done using the SPT sampler or with a maxi drive barrel & catcher. The sand/gravel layer is generally thinner than the fines layer, and may not be present at every location.

Begin the undisturbed sampling in the following holes. If problems are encountered with obtaining quality samples from one or more of these holes, another hole of the triplet may be used.

Dam Crest Triplet Hole at Sta. 14+87.5: Obtain about 5 undisturbed samples of Zone 1 core materials and about 8 undisturbed samples of foundation soils. The Zone 1 core will be encountered from about 20 feet to 120 feet deep; and the foundation soils from about 120 feet to 145 feet deep.

Upper Face Triplet Hole at Sta. 14+87.5: Obtain about 5 undisturbed samples of Zone 2 embankment materials and about 8 undisturbed samples of foundation soils. Zone 2 will be encountered from about 50 feet to 95 feet deep; and the foundation soils from about 95 feet to 120 feet deep.

Toe Triplet Holes at Sta. 6+90 and 14+90: Obtain about 8 undisturbed samples of foundation soils from each of these holes. Foundation soils will be encountered from near the ground surface to a depth of about 40 feet.

Lower Face Drill Hole (Item D) at Sta. 14+90: Obtain about 8 undisturbed samples of foundation soils. Foundation soils will be encountered from about 30 feet to 55 feet deep.

4/ Laboratory Testing

Undisturbed Samples:

The ends of each undisturbed sample tube should be plugged and sealed with O-ring packers. Each tube should be marked with the top and bottom depth interval and sampling date. Soil material trimmed from the ends of each undisturbed sample tube should be tested by the PN Region to obtain standard soils index properties including gradation (hydrometer analysis), soil consistency (Atterberg Limits), specific gravity, and moisture content. In order to obtain accurate moisture contents, samples should be obtained immediately after retrieval from the drill holes and placed in air-tight containers (not plastic bags) of appropriate size. Ideally the mass of the empty container (including any label) should be obtained and the wet mass of the soil added (container and sample). Samples placed in plastic bags could present uncertainty as to the actual moisture content.

All sample tubes should be shipped to the TSC laboratory within three days of obtaining the samples. Samples should be extruded from the tubes within seven days. The TSC laboratory will perform one-dimensional consolidation testing and unconsolidated-undrained (UU) triaxial testing on representative samples from each drill hole. Representative samples will also be tested (by a contract laboratory) for cyclic triaxial and direct simple shear (DSS) testing.

Denver, TSC Laboratory contact is Tom Strauss 303-445-2343. Shipping address:
UPS/FedEx:
Tom Strauss/ USBR
Mail Code 86-68180
Building 67, RM 152
Denver Federal Center
Denver, CO 80225.

For Freight:
Bureau of Reclamation
Tom Strauss, 86-68180
Building 810, Entrance N-9
Call Forest Roberts 303-445-3653
Denver Federal Center,
Denver, CO 80225

VST and SPT Samples:

Perform laboratory testing to obtain standard soils index properties including gradation (hydrometer analysis), soil consistency (Atterberg Limits), specific gravity, and moisture content values on all VST over-core samples and SPT samples. Samples should be placed in air-tight containers, as described above. Laboratory testing may be conducted by the PN Region contract labs.

5/ Vane Shear Testing (VST)

Perform Vane Shear Testing (VST) in the fine-grained (clayey and silty) foundation soils only. VST is not required in embankment zones or in the coarse-grained (sandy and gravelly) basal foundation unit. Vane Shear Testing should be performed in each of the holes drilled specifically for VST (Item E), in one of the Dam Crest Triplet boreholes (Item C), and one of the Upper Face Triplet boreholes (Item C). Due to the great depths to the foundation soils in dam crest and upper face holes, six-inch centralizers will be required to help center and stabilize the test rods. In these deep holes, the maximum rod torque may be reached. If the rods appear to be prone to buckling or breaking the test should be terminated.

Perform the Vane Shear Testing (VST) in accordance with ASTM procedure D 2573 using a Nilcon M-1000 Vane Borer. Field training in the use of the vane shear equipment will be provided by personnel from the TSC Engineering Geology Group. The torque head provides a paper record of each test. Push the vane in 1.5-foot increments below the bottom of the borehole, and continue pressing the vane in these increments for a distance of 10 feet. Repeat the VST for each 10-foot increment within the fine-grained foundation soils. Once the vane is retracted, the VST interval should be over-cored or drive sampled to recover samples of the tested soils. Perform a visual classification and description of the soils obtained from the sampler in accordance with **7/** below, and laboratory testing as described above in Note **4/**. Once the top of the coarse-grained basal unit is reached, testing will switch to Standard Penetration Testing (SPT) as outlined below in **6/**.

6/ Standard Penetration Testing (SPT)

Perform continuous Standard Penetration Testing (SPT) within the entire basal unit of coarse-grained foundation soils (to the top of bedrock). This basal unit was mapped in much of the cutoff trench excavation, and was encountered in some of the past exploration drill holes. Based on these data, it appears that this basal unit consists primarily of sand and gravel, and is about 5 to 10 feet thick (but may be thinner or thicker in some areas).

SPT Testing will be done using a standard penetration sampler with a constant 1-3/8 inch I.D., 2.3 foot-long split-barrel sample chamber. Continuous SPT testing is defined as one test every 2.5 feet, which includes 1.5 feet for the SPT test and a 1-foot cleanout interval. Collect penetration-per-blow data for the full 1.5-foot interval or until refusal is met. Record blow counts on a field form which shows penetration-per-blow for both the 6-inch seating interval and the 12-inch test interval. Drilling fluid level within the boreholes must be maintained at or above the in situ piezometric water level at all times during drilling, removal of drill rods, and sampling.

Perform a visual classification and description of the soils obtained from the sampler in accordance with **7/** below, and laboratory testing as described above in Note **4/**.

7/ Log drill holes in accordance with the Bureau of Reclamation Engineering Geology Field Manual, Second Edition, 1998 and Earth Manual Part 2, Third Edition, 1990. All drilling, installations, hole completion, and permits should be in accordance with the Embankment Dams Instrumentation Manual and meet State and Federal regulations and Reclamation guidelines. Photograph all samples in the field. Include a tape measure in each photograph for scale.

8/ Drilling conditions, ground water levels and fluid-loss zones are important information. Include a description of these conditions on the Daily Driller Reports. Water levels should be measured in the drill holes at the beginning and end of each shift until the PVC pipe is installed.

9/ Contact the TSC (Gary Russell at 303-445-3146 or Bill Engemoen at 303-445-2960) during these investigations to discuss progress and findings of the work. Preliminary CPT data, SPT N-values, vane shear data, crosshole velocities, and laboratory results should be sent to the TSC as soon as the information becomes available. Results from the initial investigation (such as the CPT tests) will be used for making decisions on other hole locations and test intervals.

10/ All concrete core shall be wrapped in plastic or shrink-wrapped to preserve in-situ moisture. The wrapped core shall be placed in split PVC pipe of appropriate size to protect the core and prevent it from rolling/sliding during transport. Core should be shipped to Tom Strauss as shown in Note **4/** above.

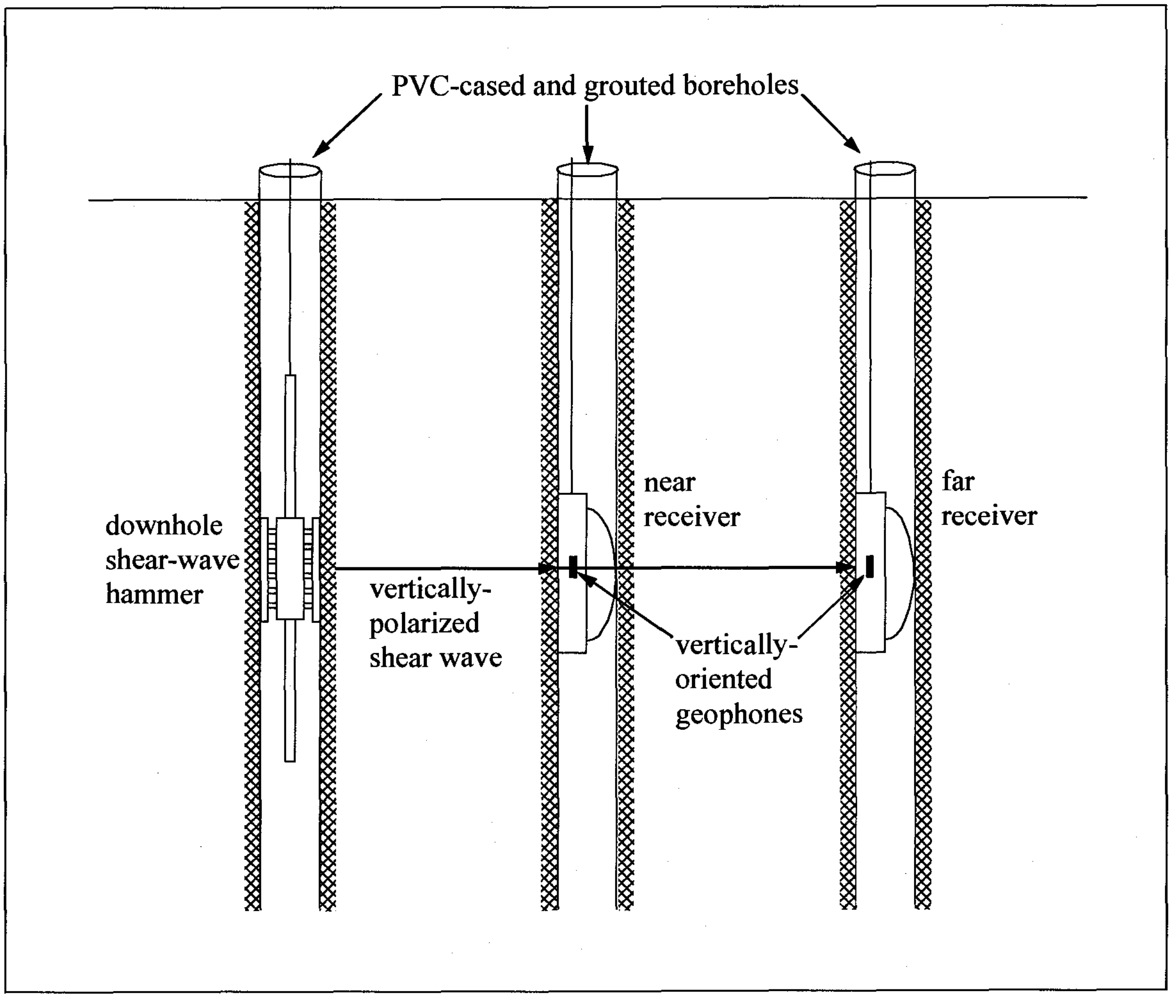
Attachment 1

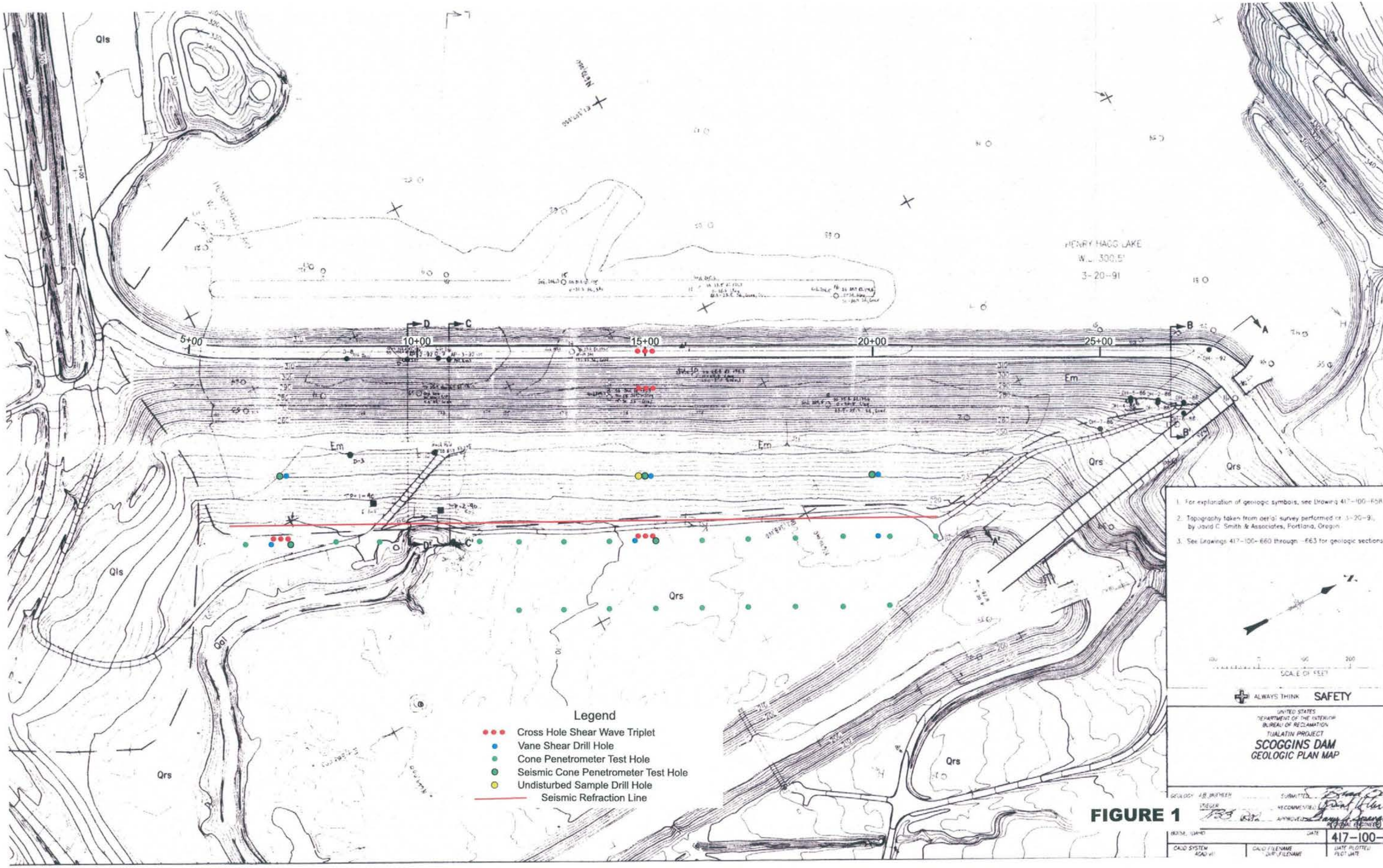
Procedures for Preparation of Boreholes for Geophysical Crosshole Testing

The method for preparing a set of boreholes for in situ crosshole testing incorporates three boreholes in line and spaced ***12.5 feet apart*** (crest and upper face holes) center-to-center and ***10 feet apart*** (toe holes) center-to-center on the ground surface, as illustrated in the following figure. The boreholes shall be drilled with minimal sidewall disturbance at a minimum diameter of 6 inches but not exceeding 8.5 inches and to a depth of 20 feet below the deepest zone of interest (20 feet into bedrock). After drilling is completed, the borings should be cased with 4-inch ID PVC pipe (flush joint). Before inserting the 4-inch PVC pipe, the bottom of the pipe shall be closed with either a cap or should have a one way ball-check capable of accommodating 1-1/2-inch (3.81 cm) OD grout pipe. The 4-inch PVC casing shall be filled with water and then grouted in place for the entire length of the borehole by inserting a 1 1/2-inch (3.81 cm) pipe through the center of the casing contacting the one-way valve fixed to the end cap, or by a small diameter grout tube inserted to the bottom of the borehole between the casing and the borehole sidewall. For holes drilled in concrete, competent rock or other earth material where casing is not required to maintain the integrity of the hole, casing need not be installed (Note: If no casing is to be installed the hole diameter should be 4 inches); however, if casing is used grout must be injected between the casing and sidewall of the borehole to ensure good contact.

When grouting through a pipe along the outside of the 4-inch casing, the portion of the boring that penetrates rock should be grouted with a conventional portland cement. The portion of the boring in contact with embankment materials, soils, sands, or gravels shall be grouted with a mixture that minimizes grout penetration into the surrounding medium and yet achieves a good bond between the outside of the casing and the unconsolidated materials. Pump the grout using a conventional, circulating pump capable of moving the grout through the grout pipe to the bottom of the casing upward from the bottom of the borehole. Using this procedure, the annular space between the sidewall of the borehole and the casing will be filled from bottom to top. Water or mud and debris should be displaced with minimum sidewall disturbance resulting in good sidewall casing contact. The grout pipe shall be removed and the grouted casing shall be capped. All boreholes shall be surveyed for location after the casing is installed. The survey shall include northing and easting grid coordinates. Borehole deviation survey will be conducted in each boring to determine accurately the horizontal distances at depth between borings.

Attachment 1 (continued)

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Legend
Cross Hole Shear Wave Triplet
Vane Shear Drill Hole
Cone Penetrometer Test Hole
Seismic Cone Penetrometer Test Hole
Undisturbed Sample Drill Hole
Seismic Refraction Line
1. For explanation of geologic symbols, see Drawing 417-100-658.
2. Topography taken from aerial survey performed on 3-20-91, by David C. Smith & Associates, Portland, Oregon.
3. See Drawings 417-100-660 through -663 for geologic sections.
SCALE OF FEET
ALWAYS THINK SAFETY
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
TUALATIN PROJECT
SCOGGINS DAM
GEOLOGIC PLAN MAP
GEOLOGY A.B. BRYHEER
SUBMITTED
RECOMMENDED
APPROVED
REGIONAL ENGINEER
BOISE, IDAHO
DATE
417-100-65
CADD SYSTEM
ACAD
CADD FILENAME
DATE PLOTTED
PLOT DATE

FIGURE 1

SCOGGINS DAM

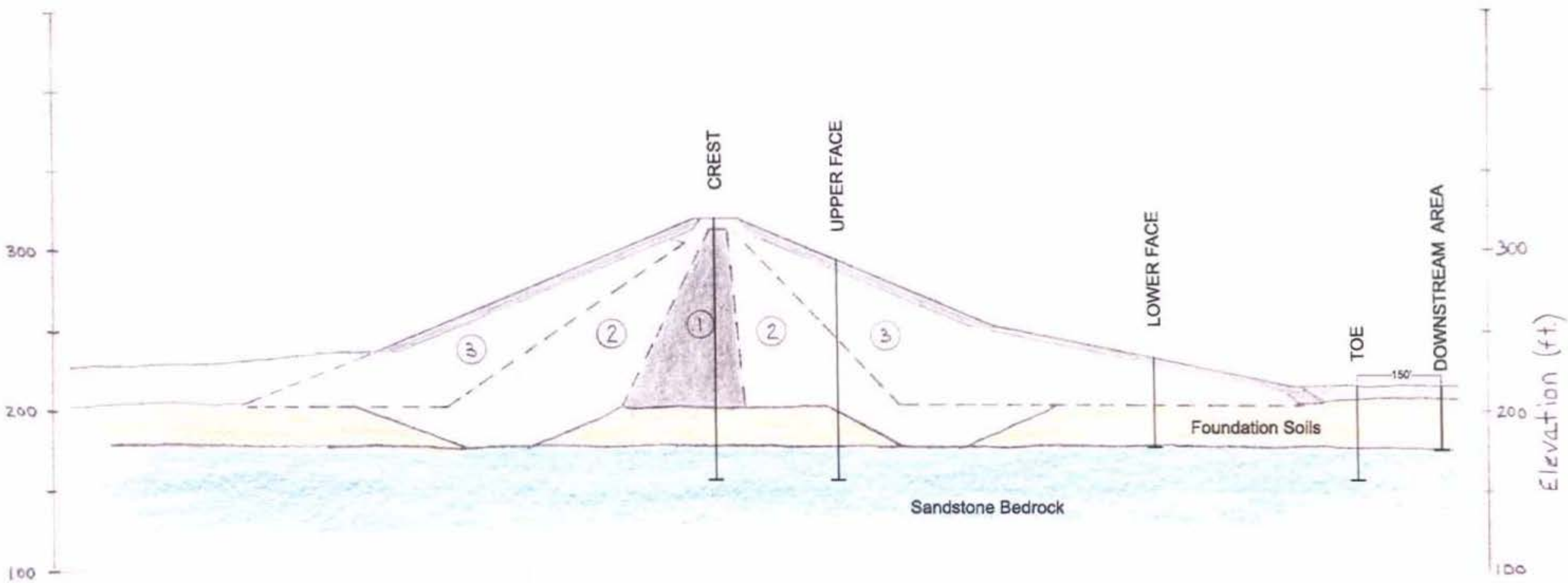

FIGURE 2

Appendix B

Procedure for Sampling and Quality Evaluation Testing of Rock for Riprap Slope Protection

Procedure for Sampling and Quality Evaluation Testing of Rock for Riprap Slope Protection

This procedure is under the jurisdiction of the Materials Engineering and Research Laboratory, code 86-68180, Technical Service Center, Denver, Colorado. The procedure is issued under the fixed designation USBR 6025. The number immediately following the designation indicates the first year of acceptance or the year of last revision.

1. 1. Scope

1.1 *Application.*-This designation covers the sampling and quality evaluation testing of rock from operating quarries, potential quarries, talus slopes, or stream-deposited boulders for slope protection (riprap).

1.2 *Additional Use.*-This procedure also provides useful information for:

- Control of operations at the source of supply
- Control of operations at the cite of use
- Acceptance or rejection of materials

1.3 *Units.*-The values stated in SI/metric (inch-pound) units are to be regarded as standard.

1.4 *Caveats.*-This designation does not purport to address all the safety issues associated with its use and may involve use of hazardous materials, equipment, and operations. The user has the responsibility to establish and adopt appropriate safety and health practices. Also, the user must comply with prevalent regulatory codes while using this procedure.

2. Applicable Documents

2.1 USBR Procedures:

USBR 4075 Sampling Aggregates

USBR 4088 Soundness of Aggregates Using Sodium Sulfate

USBR 4127 Specific Gravity and Absorption of Coarse Aggregate

USBR 4131 Resistance to Degradation of Small Size, Coarse Aggregate by Abrasion and Impact in Los Angeles Machine

USBR 4295 Petrographic Examination of Aggregate for Concrete

USBR 4666 Resistance of Concrete to Rapid Freezing and Thawing

USBR 4702 Reducing Field Samples of Aggregate to Testing Size

2.2 ASTM Documents:

ASTM C 294 Standard Descriptive Nomenclature for Constituents of Natural Mineral Aggregates

ASTM D 4992 Standard Practice for Evaluation of Rock to be Used for Erosion Control

ASTM D 5121 Standard Practice for Preparation of Rock Slabs for Durability Testing

2.3 Other Documents:

Design Standards No. 13- Embankment Dams, Chapter 7 - Riprap Slope Protection - Bureau of Reclamation, 1992.

Report No. REC-ERC-73-4 - Riprap Slope Protection for Earth Dams: A Review of Practices and Procedures.

OSHA Regulations (29 CER, CH. XVII, 1926.900-.950, 1989), Blasting Safety.

Design of Small Dams, Bureau of Reclamation, 3rd Edition, 1987.

Engineering Geology Office Manual, Bureau of Reclamation, 1988.

Engineering Geology Field Manual, Bureau of Reclamation, 1989.

Construction Safety Standards, Bureau of Reclamation, 1987.

Petrographic Laboratory Analytical Techniques and Capabilities Reference, pp. 6-8, Bureau of Reclamation, September 1985 .

3. Summary of Method

This procedure describes the various states of riprap investigations. Representative rock samples obtained from quarries, borrow areas, or talus slopes are petrographically classified and physical properties (including freeze-thaw durability> are determined. Laboratory test data are used to evaluate rock quality sad suitability for potential riprap slope protection placements in critical structure zones subject to severe wave action and environmental exposure conditions

4. Significance and Use

4.1 *Slope Protection.*-This practice provides recommendations for investigation, sampling, and quality evaluation testing of riprap rock fragments for use as slope protection. Production sources should produce rock fragments in suitable sizes for the required usage. The fragments should be sufficiently hard, dense, and durable to withstand processes in procurement, transportation, placement, weathering, and the physical forces of nature such as wind and wave action, freezing and thawing, wetting and drying, as well as heating and cooling. Investigations must identify a sufficient quantity of material of required quality.

4.2 *Embankment Dams.*-Most embankment dams built by Reclamation contain one or more zones that require the production of rock. The rock is used as riprap for protection against erosion, or as rockfill or filter zones that strengthen or drain the embankment, thereby increasing its degree of stability. Riprap blankets are also commonly required below spillway and outlet works stilling basins and for canal and channel protection.

4.3 *Preparation.*-Production of such rocks generally requires drilling, blasting, and processing to obtain the required sizes.

4.4 *Riprap.*-Igneous, metamorphic, and sedimentary rocks can be used for the production of riprap.

5. Apparatus

5.1 *Excavating Equipment.*-Equipment such as bulldozers, backhoes, draglines, bucket augers, core drills, and jackhammers.

5.2 *Blasting Equipment.*-Dynamite, blasting caps, and drills for providing holes for setting blasting charges.

5.3 *Production evaluation.*-Survey equipment and truck weigh scales for production evaluation.

5.4 *Saw.*- A diamond, slab, or other saw of suitable size and quality to prepare cubical rock specimends from the sample.

5.5 *Miscellaneous Materials*.-Bags and pallets for transporting and handling samples.

6. Precautions

6.1 *Hazardous Materials.*-This test procedure may involve hazardous materials, operations, and equipment and does not claim to address all safety problems associated with its use. The user has the responsibility to consult and establish appropriate safety and health practices and determine applicability of regulatory limitations prior to use.

6.2 *Qualified Personnel.*-Personnel shall be well versed in handling the above equipment. Only qualified and authorized persons shall be permitted to handle and use explosives.

6.3 *Safety Standards.*-Blasting safety must be executed in accordance with Reclamation Construction Safety Standards and the OSHA regulations (29 CFR, CH.XVII, 1926.900- .950, 1989) whichever is more stringent.

7. Source Investigation Stages

7.1 *General*-The complexity of investigations to determine suitable sources of riprap materials will be governed by project development stage and design requirements of the project features, Normally, project development occurs in four stages: reconnaissance, feasibility, specifications, and construction.

7.1.1 *Reconnaissance*.-Initial or preliminary exploration involves field surface reconnaissance using topographic, geologic, and agricultural soil maps and aerial photographs with supplemental information provided by records of known developed sources of material. A study of maps and aerial photographs may reveal possible sources of material. Contours are often an indication of the type of material; sharp breaks usually indicate hard rock, and slopes below cliffs often have talus deposits. During field reconnaissance, the countryside should be examined for exposed rock outcrops or cliffs. Road cuts and ditches may also reveal useful deposits. Data obtained should define the major advantages or disadvantages of potential materials sources within reasonable haul distance to the job site. Reporting accumulated data and information at this stage of investigation is accomplished by construction materials reports to the Technical Service Center.

7.1.2 *Feasibillity*.-Information accumulated during this stage is needed to prepare preliminary designs and cost estimates. Sufficient information concerning potential sources should be gathered to determine whether the Government should acquire the source or if the rock should be furnished by the contractor. Selection of sources should be limited to those which may eventually be cited in specifications. Core drilling or blast tests may be required to confirm fragment size and quantity of material available in the sources. The potential material sources are examined to determine size and character, and particularly to observe joint and fracture spacing, resistance to weathering, and variability of the rock. The spacing of joints, fractures, schistosity, lineations, bedding, and other planes of weakness may control the size of rock fragments obtainable from the deposit. Observation of weathering resistance of rock *in situ* will provide a good indication of its durability. Particular attention should be given to location and distribution of unsound seams or strat which must be avoided or wasted during quarrying operations. A general location map and report describing the potential sources and containing estimates of available quantities, overburden, haul roads, and accessibility are prepared. Representative samples of riprap material from the most promising potential sources are required to be submitted to the Materials Engineering and Research Laboratories in Denver or other approved laboratory for quality evaluation tests. The extent and detail of information necessary at this stage is described in section 7.

7. 1.3 *Specifications.*-Investigations at this stage furnish design data and information required for specifications preparation. Exploration requests issued by the Technical Service Center will define requirements for riprap materials investigations. Sources indicated by feasibility investigation data to be of suitable quality for project feature work are surveyed and investigated to establish the quantity of material available and determine its uniformity.

7.1.3.1 Core drilling may be required, if dictated by geologic conditions. Such core drilling should be done on a grid system, if appropriate, and should include both vertical and angled holes as directed by the geologist or materials engineer. Blast testing should also be done at this time if not performed previously. Blast testing data shall be submitted to the Technical Service Center in the form of construction reports suitable for reference by the specifications. Sampling and testing should also be completed during this stage.

7.1.3.2 If additional deposits are considered at this stage, they must be investigated as thoroughly as the originally considered source or sources.

7.1.4 *Construction.*-Investigations during the construction stage are sometimes required to provide field and design personnel with additional detailed information for proper source development. This information should be obtained sufficiently ahead of quarrying or excavation operations to provide for proper processing and placing of material. If unforeseen changes occur in quality of material being removed from the source, sampling and quality evaluation testing of the rock may be required to confirm material suitability or delineate unsuitable rock areas.

8. Source Information

8 1 *Background.*-Reporting information and data accumulated during any investigation stage is most important. Although detailed information requirements increase with each successive stage, adequate information must be available by the feasibility stage to develop realistic cost estimates and properly select sources for possible use.

Required data obtained earlier than needed should be submitted when available and not withheld. For feasibility studies, the designers should have sufficient information to supplement laboratory test data to determine whether the Government should acquire the source, whether the rock should be furnished by the contractor, or whether other types of embankment protection should be considered. A suggested outline for riprap reports for rock obtained from an undeveloped quarry is:

a. Ownership

b. Location, indicated by map, with reference to the U.S. Public Land Survey legal description (section, township, range, and meridian). If, as will be the case in unsurveyed areas, the legal description is unavailable, the latitudinal and longitudinal coordinates (degrees, minutes, and seconds) should be obtained.

c. General description

d. Geologic type arid classification

e. Joint spacing and fracture systems

f. Bedding and planes of stratification

g. Manner and sizes in which rock may break on blasting as affected by jointing, bedding, or internal stresses

h. Shape and angularity of rock fragments

i. Hardness and density of rock

j. Degree of weathering

k. Any abnormal properties or conditions not covered above

l. Thickness, extent, estimated volume, and average depth of deposit type, extent, and thickness of overburden

m. Accessibility (roads affording access to highways or railroad, giving distance, load limitations, required maintenance, whether privately owned, and other pertinent information)

n. Photographs and any other information which may be useful or necessary

8.2 *Quarry*.-If commercial quarry deposits are considered, the following information should be obtained and included in the report:

a. Name and address of plant operator; if quarry is not in operation, a statement about ownership or control

b. Location of plant and quarry

c. Age of plant (if inactive, approximate date when operations ceased)

d. Transportation facilities and difficulties

e. Deposit extent, plant and stockpile capacity

f. Plant description (type and condition of equipment for excavating, transporting, crushing, classifying and loading, and restrictions, if any)

g. Approximate percentages of various sizes of material produced by the plant

h. Location of scales for weighing shipments

i. Approximate prices of materials at the plant

j. Principal users of plant output

k. Service history of material produced

l. Any other pertinent information

8.3 *Nonquarry.*-When rock deposits other than quarries are considered for riprap use, the rock properties and deposit should be described in the same manner as for quarry rock where applicable and, in addition, the deposit description should indicate shape, average size, and variation in sizes of the rock.

8.4 *Data Sheet.*-A typical source information data sheet is shown on figures 1 and 2.

9. Sampling

9.1 *Representation.*-Sampling, often a weak link in the chain of investigative procedures, is equally important as testing, and the sampler shall use every precaution to obtain samples that will show the nature and condition of the materials which the samples represent. Thus, sampling must be carefully performed by qualified, experienced personnel.

9.2 *Reports.*-Sampling is initiated at the specifications development phase of the project. Sampling is requested by exploration or design data requests, which should delineate size and location requirements for the riprap source. Detailed reports of investigations are submitted to the Technical Service Center as part of design data or Construction Materials reports.

9.3 *Size.*-The sample size should be at east 275 kg (600 lbm) and represent proportionally the quality range from poor to medium to best as found at the source. If the material quality is quite variable, it may be preferable to obtain three samples which represent, respectively, the poorest, medium, and best quality material available. The minimum size of individual fragments selected should be at least 0.014 m^3 (1/2 ft^3) in volume, if possible. An estimate of the relative percentages of each material quality should be made and included as information relating to the source. Samples from undeveloped sources must be very carefully chosen so that the material selected will, as far as possible, be typical of the deposit and include any significant rock-type variations.

9.3.1 Representative samples may be difficult to obtain. Overburden may limit the area from which material can be taken and obscure the true character of a large part of the deposit. Surface outcrops will often be more weathered than the 'interior of the deposit. Samples obtained from loose rock fragments on the ground or collected from weathered outer surfaces of rock outcrops are seldom representative. Fresh material may be obtained by breaking away the outer surfaces, or by trenching, blasting, or core drilling. In stratified deposits such as limestones or sandstones, vertical and horizontal uniformity must be evaluated, as strata often differ in character and quality.

9.3.2 The dip of stratified formations must also be considered. Strata inclination with respect to surface slope will expose different strata at the surface in different parts of the area. Attention should be directed to the possibility of zones or layers of undesirable material. Clay or shale seams may be so large or prevalent as to require selective quarrying or excessive wasting of undesirable material.

9.4 Shipping Samples:

9.4.1 Samples of rock fragments can be shipped by conventional transport such as motor freight. Large rock fragments should be securely banded to shipping pallets. Smaller fragments should be transported in bags or containers to preclude loss, contamination, or damage from mishandling during shipment.

9.4.2 Shipping containers for rock fragments shall have suitable individual identification attached and enclosed. A data sheet outlining details of the shipped sample should be included. It is often desirable to identify individual rock fragments by painted numbers or similar markings.

10. Procedure

10.1*Tests.*-Quality evaluation tests performed in the Technical Service Center laboratories on representative samples submitted from the field include detailed petrographic examination, determination of physical properties, and rapid freeze-thaw durability tests. These tests serve as a guide for determining if the material can be considered acceptable for use as riprap or rockfill material

10.2 *Petrographic Examination*.- Laboratory petrographic examination procedures for riprap/rockfill materials are not detailed, but USBR 4295 (although developed for concrete aggregate) may serve as a guide. Decisions concerning specific procedural methods and specimen preparation depend upon the nature of the rock, the intended usage of the rock, and the petrographer's judgment.

102.1 The rock pieces comprising the sample are visually examined and different rock facies and rock types, if present, are segregated for individual evaluation. The size range and characteristic fragment shapes are noted. The rock pieces are studied to evaluate if fragment shape and/or size is determined by discontinuities such as joints, fractures, bedding planes, or shear zones. Surface weathering and secondary deposits of alkali salts or clay are noted. Fracture or vein systems are described as well as the ease with which fractures or veins can be opened. Hardness, toughness or brittleness, and visible voids or pore characteristics and their variations are noted, The texture, internal structure, grain size, and mineralogy of the various facies and rock types are determined. Special attention is given to internal voids and fractures and to the type and amount of cementing material in sedimentary rocks. Thin section analyses, sometimes supplemented by X-ray diffraction analysis, are made as required.

10.3 *Freeze-Thaw Test Specimen Preparation*-For freeze-thaw durability testing, 73-mm (2 7/8-in) cubes are sawed from rock fragments selected by visual inspection to represent the poorest, medium, and best quality rock for each rock facies or type. Because the rock pieces could exhibit significant physical or structural features (e.g., joints, fractures, bedding planes), the number of cubes obtained for testing will vary from sample to sample. Prior to freeze-thaw testing, 'before test" photographs are taken and oven-dry cube masses are determined. Before testing, the cubes are immersed in water for 72 hours and specific gravities (bulk oven-dry, bulk saturated-surface-dry, and apparent) and absorptions are determined by USBR 4127. The cubes are reimmersed in water to maintain a saturated condition for freeze-thaw testing.

10.4 *Freeze-Thaw Test Performance.*-Rapid freezing and thawing durability tests (USBR 4666) are performed on all riprap samples, including those from areas not subject to freeze-thaw environments. The test detects structural weaknesses and is a good indicator of potential rock durability.

10.4.1 After saturated-surface-day cube masses are determined, the cubes are inserted in 76-mm (3-in) square rubber sheaths and sufficient water is added to cover the specimens. The rubber sheaths containing the specimens are placed in automatically controlled freezing and thawing cabinets, where the cubes are subjected to rapidly repeated eyelet of freezing and thawing in water, Each cycle consists of 1½ hours freezing at -12 °C (10 °F) and 1½ hours thawing at 21 °C (70 °F). During the test, cube mass loss determinations are made at periodic intervals and the appearance and manner of cube deterioration is noted. Termination of the test is 250 cycles or when the rock splits or fails (see section 10.4.2).

10.4.2 The criterion for rock failure is 25 percent loss of cube mass calculated from the difference in mass between the largest cube fragment remaining after testing and the initial cube mass. Cube specimen failure modes (e.g., splitting, disaggregation, popouts, exfoliation) are noted and "after test" cube photographs are taken. Apparent and actual mass loss values are calculated when a cube specimen fails along preexisting fractures, joints, bedding planes, or stylolites into a few large fragments. Apparent mass loss is calculated as described above, using the mass of the largest remaining fragment. Actual mass loss is calculated from the difference between the combined masses of all fragments remaining after testing and the initial cube mass.

10.5 *Physical Properties Sample Preparation and Testing* -Material remaining after petrographic examination of the rock sample (excluding any pieces selected for more detailed petrographic analysis and freeze-thaw durability tests) is crushed into 37.5- to 75-mm, 19.0- to 37.5-mm, 9.5- to 19.0- mm, 4.75-109,5-mm (1½- to 3-in. 3/4 to 1½-in, 3/8-to 3/4-in, and No. 4 to 3/8-in) size fractions. Representative samples of each size fraction are obtained for physical properties tests (USBR 4702). Physical properties tests performed on the various size fractions of crushed material are: (a) bulk saturated-surface-dry specific gravity and absorption, USBR 4127; (b) Los Angeles abrasion, USBR 4131; and (c) sodium sulfate soundness, USBR 4088. Typical laboratory work forms appear on figures 3 and 4.

Note 1.-Representative samples are also obtained for petrographic examination if the material is to be evaluated for use as crushed concrete aggregate.

11. Riprap Quality Evaluation Report

11.1 *Rock Type.*-Rock for riprap should be hard, dense, durable, resistant to abrasion, and free from discontinuities that will tend to increase destruction or displacement by wave action or exposure to various environmental conditions such as wetting and drying, heating and cooling, and freezing and thawing. Structural design requirements vary and each site presents unique problems. To allow designers to work within these structural and environmental parameters, the standard Reclamation riprap quality evaluation for slope protection is based upon material requirements for placements in critical zones, frequently inundated for long periods of time with fluctuating water levels, and subject to heavy wave action and severe environmental exposure conditions. Economic factors are also considered in selection of riprap material sources.

11.2 *Test Significance.*-Riprap quality evaluation reports are based on physical properties test data, freeze-thaw durability, and petrographic examination. In Reclamation's experience, no single specific test has proven to be of significantly greater importance in evaluating rock quality for riprap usage than any other single test. Petrographic analysis (although a subjective evaluation) and freeze-thaw durability tests generally provide the most reliable and consistent measure of riprap quality. Each potential riprap material is judged independently with all available test data considered. The significance of test data is discussed, if appropriate, because some materials are suitable for slope protection even though the test data indicate the rock to be of marginal or poor quality. If applicable, recommendations are presented for improving and extending the life and durability of a riprap blanket.

11.3 *Report Form.*-A typical riprap quality evaluation report form is shown on figure 5.