# CHAPTER 7. DETAILED SITE INVESTIGATION

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TABLES

# CHAPTER 7. DETAILED SITE INVESTIGATION

A detailed site investigation provides information on subsurface conditions that cannot be obtained by surface examination or by shallow subsurface investigation in which readily portable tools such as hand shovels and hand augers are used. Usually, detailed subsurface investigations require equipment such as backhoes, dozers, power augers, or core drills.

Detailed site investigations are required if information about the geology of the area is not adequate or if the results of the preliminary geologic examination are not sufficiently conclusive to positively establish that:

1. Knowledge of the foundation materials and conditions to a depth at least equal to the height of the proposed structure is of sufficient scope and quality to serve as a basis for geologic interpretation and structural design.
2. Fill materials of suitable quality are available in sufficient quantity.
3. The reservoir basin of storage reservoirs is free from sinks, permeable strata, and fractures or fissures that might lead to moderate or rapid water loss.
4. Subsurface water conditions that might materially affect the design of the structure or the construction operations are known.
5. Stability characteristics of material in the emergency or other open spillways and channels under anticipated flow conditions during operation of the structure are known.
6. The probable rate of sedimentation of the reservoir will not encroach upon the usable storage capacity in a period of years less than the designed life expectancy of the structure.

Detailed subsurface investigations must be of sufficient intensity to determine all the conditions or factors that may influence the design, construction, or functioning of the structure.

Subsurface investigations of dam sites are made after the surface geology has been studied. The nature and intensity of underground exploratory work for a particular type and purpose of structure are conditioned by this earlier examination of the area. As subsurface work progresses, the findings may further modify the intensity of investigation needed. Other conditions being equal, the intensity of investigation depends on the complexity of the site.

It is desirable for the operations geologist to inspect dam sites during construction to get a better understanding of construction procedures, to observe subsurface conditions that are exposed, and to confer with the engineer on any problems involving geology that develop.

Detailed subsurface investigations can be carried out under contract with local companies or by SCS personnel using SCS-owned equipment.

## Contracting for Geologic Investigations of Dam Sites

In those States where the annual workload is not large enough to justify the purchase of drilling equipment, drilling services must be obtained for subsurface investigations by arrangement with other States or by contracting with private companies. These services may be obtained by (1) equipment-rental contract or (2) inclusion in a negotiated engineering contract for professional services (see Engineering Memorandum SCS-36). If an equipment-rental contract is let, logging and classifying materials, developing interpretations, and preparing the reports are the responsibility of SCS personnel. In a negotiated engineering contract for geologic investigations, the contractor is required to provide and operate exploration equipment, to log and classify the materials, and to prepare the geologic report. A negotiated engineering contract can be let solely for geologic investigations including analysis and reports, or these investigations can be included in an overall contract that also includes laboratory analysis and development of the final design.

Minimum requirements and technical standards for SCS work are the same for contracted work as for work done with SCS owned and operated equipment.

## Preparation for Subsurface Exploration

### Assembling Maps, Reports, and Basic Data

Available geologic information may indicate the intensity of investigation needed. Review the data collected during the preliminary geologic examination and the report of that examination in detail. This study may indicate the extent to which additional information and data are needed. The sources of information suggested under Assembly of Data in chapter 6 may furnish more data on problems that may be present.

Before the field work is started, the engineering-survey information and any available preliminary design data should be plotted on forms SCS-35A, -35B, and -35C so that the geologist can locate and log the test holes and correlate between them.

The preliminary plan of the proposed structure, including the centerline of the dam and the proposed centerline of the principal outlet structure and emergency spillway, the present stream channel, and a map of the proposed borrow area(s) containing grids or traverse reference are prepared on form SCS-35A. Cross sections of the borrow area are to be drawn on this sheet as the investigation proceeds.

The profiles of the proposed centerline of the dam and the principal spillway are prepared on form SCS-35B. If cross sections of the stream channel are needed, they are to be plotted on this sheet as the investigation proceeds.

Form SCS-35C includes the proposed centerline of the emergency spillway and provides space for the cross sections of the emergency spillway that are developed during the course of the investigation. If needed, form SCS-315 may be used for additional profiles and cross sections, such as the profile in the downstream part of the dam if borings are needed for toe drains or relief wells.

Necessary Authorizations

It is essential always to obtain the landowner's permission to enter, cross, and exit from his land or property. Permission is also required if property is to be removed (temporarily or permanently), displaced, or rearranged. Permission is required for construction of roads, sumps, ditches, or ramps; for use and discharge of water belonging to the property owner; for construction of exploratory trenches, auger holes, drill holes, and test pits; and for stream displacement or obstruction. The necessary clearance is to be obtained by the Work Unit Conservationist.

Preparation of Site

If the activities of the survey crew and the investigation party are well coordinated, the dam and reservoir areas should be mapped, staked, and adequately cleared before equipment for subsurface investigation arrives.

Staking and Clearing

Locations of the centerline of the dam, centerline of the principal spillway, and cross sections of the emergency spillway should be staked. In many cases it is desirable to survey and stake an alternate location for the principal spillway. In areas of tall grass or weeds, lath and flagging should be used to locate the stakes.

All grid lines in the borrow area, emergency-spillway cross sections, centerline of the principal spillway, and centerline of the dam should be cleared to a width sufficient to provide easy access for the drilling equipment. If a stream crossing must be provided, it may have to be located upstream from the reservoir to avoid modifying the ground-water conditions at the site.

## Subsurface Exploration
## Phase 1: Geologic Correlation and Interpretation

Purpose and Objectives

The purpose of phase 1 of the detailed subsurface investigation is to identify, delineate, and correlate the underlying materials; to locate, identify, and interpret geologic features; to determine ground-water conditions; to interpret, to the extent possible by field tests, the engineering properties of the materials; and to determine what materials need to be sampled for soil mechanics tests.

Split-tube or thin-wall drive samplers are recommended for exploratory boring. For accurate logging of unconsolidated thin-bedded and highly variable materials, thin-wall or split-tube drive samplers must be used. Thin-wall drive samplers can be used for this purpose only if the drilling rig is equipped with a suitable device for extruding samples.

The number, distribution, and size of test holes and the number of samples needed to establish subsurface conditions vary widely from one investigation to another, depending on the variety and complexity of the conditions. Enough test holes of adequate depth must be bored for the geologist to identify, delineate, and correlate the underlying strata and for the engineer and the geologist to determine the kinds and locations of samples needed. Where experience or previous examination indicates that only shallow test holes are needed, the excavation of open pits with hand tools or dozers and backhoes may be adequate. Where there are numerous cobbles and boulders, backhoe or dozer pits may be the most practical method of exploration. Where pits and trenches in the foundation area cannot be left open, record their location and extent accurately and show them on the plan so that, if necessary, they can be reopened and properly sloped and backfilled during construction.

Numbering Test Holes

Use the following standard system of numbering test holes.

| Location | Hole Nos. |
|---|---|
| Centerline of dam | 1-99 |
| Borrow area | 101-199 |
| Emergency spillway | 201-299 |
| Centerline of principal spillway | 301-399 |
| Stream channel | 401-499 |
| Relief wells | 501-599 |
| Other | 601-699 |
| Other | 701-799, etc. |

Principal-spillway, channel, and emergency-spillway holes that are on the centerline of the dam should be given principal-spillway, channel, and emergency-spillway Nos. rather than centerline-of-dam Nos. Number foundation holes in the area of the base of the dam but not in the immediate vicinity of the centerline of the dam or appurtenances as "other."

Determining Location and Depth of Proposed Test Holes

Make exploratory borings along the centerline of the dam, along the centerline of the outlet structure, in the spillway area, and in the borrow area or areas. Additional exploratory borings will be needed if relief wells or foundation drains are required or if special information is needed because of site conditions.

Foundation test holes.--Centerline investigations must determine whether there is stable support for the dam; whether all strata have enough strength to prevent crushing, excessive consolidation, or plastic flow; and whether water movement through the foundation or abutments will cause piping, detrimental uplift pressure, or excessive water loss.

Conditions that must be recognized and located include nature, extent, and sequence of strata; highly dispersed soils; soluble salts; aquifers; and any weak bedding planes, joints, faults, or other structural weaknesses in the underlying formations.

The spacing and number of test holes needed along the centerline of the dam or beneath the proposed base depend principally on the complexity of the geology. Some of the more important factors are character and continuity of the beds, attitude of the strata, and presence or absence of joints or faults. Depth, thickness, sequence, extent, and continuity of the different materials must be determined.

A convenient system of boring to determine site conditions is to locate one test hole on the flood plain near each abutment and one on the centerline of the outlet structure. Between these holes additional holes may then be located as needed to establish good correlation of strata. At least one hole should be put in each abandoned stream channel that crosses the centerline. At least one hole is usually required in each abutment unless a good surface exposure is available. It is highly important that enough investigation be carried out to establish continuity of strata, or the lack thereof, throughout the area underlying the base of the proposed dam.

In addition to the minimum requirements for depth of exploration set forth in chapter 5, the following criteria apply to foundation investigations.

Investigations must proceed to a depth of not less than the height of the dam unless unweathered rock is encountered. For this purpose rock is interpreted as indurated, virtually incompressible material that is not underlain at least for a depth equal to the height of the dam by unstable, compressible materials. Usually rock includes shale and siltstone. Experience and knowledge of the general stratigraphy of the area may provide information on the thickness of these rock formations. The lack of positive information about the formations makes it necessary to drill an exploratory hole to the "minimum" depth specified, as if the formation were unconsolidated material.

Where compressible material extends to a depth equal to the maximum height of the dam, it may be necessary to extend exploration to a much greater depth. Depth of exploration depends on the character of material and on the combined pressure exerted by overburden and embankment. Tables 7-1 and 7-2 will help the engineering geologist to make this decision. Table 7-1 shows the approximate loading values of earthfill structures of various heights of fill at various depths. For example, a dam 50 feet high exerts a downward pressure of about 1.9 tons per square foot at a depth of 50 feet directly below the centerline of the dam. This is only an approximate value because load varies with density of the fill material, shape and rigidity of the dam, and strength of the foundation material above the point of measurement.

Table 7-2 shows the presumptive bearing values of various unconfined materials for different consistencies and relative densities. These values are the approximate loads to which these various soil materials can safely be subjected without excessive settlement. This is somewhat ambiguous because a given amount of settlement per unit thickness may be of minor significance for a thin layer but excessive for a thick stratum.

The estimate of consistency and relative density must be made from examination of representative samples, blow count, drilling characteristics, or an estimate of the dry density and void ratio of the material.

An example of how to use tables 7-1 and 7-2 follows. The foundation for a dam 50 feet high has been drilled to the minimum depth of 50 feet, and the bottom of the bore hole is still in compressible materials. The approximate vertical stress at this depth from a 50-foot dam is 1.9 tons per square foot (table 7-1). The material at the bottom of the hole is a stiff inorganic plastic clay (CH). Table 7-2 shows that stiff CH has a presumptive bearing value of 1.5 tons per square foot. This indicates that the formation is subject to deformation under the proposed load and that exploration must continue to a greater depth until the vertical stress is equal to or less than the safe load value (in this example at a depth of 85 feet).

Since these are approximate values, use them only as guides for increasing the minimum depth of exploration. Do not use them for design. Never use the tables as justification for terminating exploration at a depth of less than the minimum set forth in chapter 5.

Principal-spillway test holes.--Complete information on the strata underlying the outlet structure is needed to design the outlet structure. It is necessary to determine if there is likely to be appreciable differential settlement that may result in cracking. If the outlet conduit is to be located on or near rock with an irregular surface, the profile of the rock surface must be accurately defined. The number of test holes needed for this purpose depends on the configuration of the rock. If the rock surface is undulating, numerous test holes may be required so that the needed depth of cradle and the treatment of the foundation can be determined. In addition to the test hole at the intersection of the centerline of the dam and other holes needed to determine the configuration of rock, test holes are needed at the proposed riser location, at the downstream toe of the dam, and at the downstream end of the outlet conduit. For other types of outlets exploration requirements vary widely from site to site, but boring must be adequate to permit the design of structures that are safe insofar as bearing and sliding are concerned.

The minimum depth of holes along the centerline of the outlet is to be equal to the height of the proposed fill over the outlet conduit at the location of boring or 12 feet, whichever is greater, unless unweathered rock is encountered. The minimum depth of holes below the riser is to be equal to the difference in elevation between the top of the riser and the natural ground line or 12 feet, whichever is greater.

Emergency-spillway test holes.--It is necessary to determine the stability and erodibility of spillway material and to provide adequate information on the extent and volume of the various types of material to be excavated and on the suitability of the excavated material for use in construction. A series of geologic cross sections at right angles to the centerline of the spillway should be developed if conditions are highly variable or if long spillway sections are planned.

Table 7-1.--Approximate vertical-stress values of earthfill structures weighing 100 pounds per cubic foot[1]

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

[1] Do not use for design purposes.

Table 7-2.--Presumptive bearing values (approximate maximum safe-load values) of soils as related to the Unified soil classification system

Noncohesive materials

| Relative density[1] | GW | GP | SW | SP | GM | GC | SM | ML |
|---|---|---|---|---|---|---|---|---|
| | Tons per square foot | | | | | | | |
| Very loose. | -- | -- | 0.50 | 0.50 | 0.25 | 0.25 | < 0.25 | -- |
| Loose...... | 1.75 | 1.75 | 1.00 | 1.00 | .50 | 1.25 | .75 | 0.25 |
| Medium or firm. | 3.50 | 3.25 | 2.25 | 2.00 | 1.40 | 2.40 | 1.75 | 1.00 |
| Dense or compact. | 5.25 | 5.00 | 3.75 | 2.25 | 2.80 | 3.50 | 2.50 | 1.75 |
| Very dense or very compact. | 6.00 | 5.75 | 4.50 | 3.25 | 3.50 | 6.25 | 3.00 | 2.00 |

Cohesive materials

| Consistency[1] | SM | SC | ML | CL | OL | MH | CH | OH |
|---|---|---|---|---|---|---|---|---|
| | Tons per square foot | | | | | | | |
| Very soft.. | 0.25 | 0.25 | -- | 0.25 | -- | -- | -- | -- |
| Soft....... | .50 | .50 | 0.25 | .50 | -- | 0.25 | 0.25 | -- |
| Medium..... | .75 | 1.00 | .75 | 1.00 | 0.25 | 1.00 | 1.00 | 0.25 |
| Stiff...... | 1.50 | 2.25 | 1.75 | 2.25 | 1.00 | 2.25 | 1.50 | 1.00 |
| Very stiff. | 2.00 | 2.75 | 2.00 | 2.75 | 1.50 | 2.75 | 1.75 | 1.25 |
| Hard....... | 2.50 | 3.25 | 2.50 | 3.25 | 2.00 | 3.25 | 2.25 | 1.50 |

[1] Relative density and consistency as related to standard penetration test (table 2-1).

Initially, one cross section should be located approximately at the control section, one in the outlet section, and one in the inlet section of the spillway. Additional cross sections can then be located as needed for correlation, to locate contacts, or to obtain additional needed data. On each cross section, test holes should be located at the centerline and at the sides of the spillway. Where deep spillway cuts are planned, additional test holes may be needed to determine the character of the material in the sides of the cut. Where there is consolidated rock, it is important to carefully delineate the rock surface. The number of additional cross sections or test holes that may be needed for this purpose depends on the configuration of the rock. Each boring for emergency-spillway investigations must extend to a depth of not less than 2 feet below the bottom of the proposed emergency spillway.

Investigations for rock excavation must be of sufficient detail that the estimate of quantity is no more than 25 percent in error. Boring must extend to a depth of at least 2 feet below the level to which excavation is planned. This usually requires drilling equipment even where delineation of the rock surface has been accomplished by using a bulldozer or backhoe. Carefully log and describe the material to be excavated. Give special attention to such structural features as thickness of beds; attitude, character, and condition of bedding planes; joint systems and attitude and condition of joint planes; schistosity; cleavage; flow banding; and cavities and solution channels as well as to strength (chapter 1) and degree and kind of cementation. These factors influence the method and hence the cost of excavation. Under some combinations of these conditions rock can be ripped and removed, other combinations may require special equipment, and still others blasting.

Borrow-area test holes.--The proposed borrow area is investigated to identify and classify the materials according to their availability and suitability for use in constructing the dam. From these investigations the location and quantities of desirable materials and the areas in which borrow pits may be most conveniently developed can be determined. The location and approximate extent of any undesirable materials must be determined. Depth to ground water, if reached, must be recorded.

The initial location of test holes in the borrow area should be according to some systematic plan, such as intersections of a grid system, so that the area is adequately covered by a minimum number of holes. Additional holes can then be located where they are needed to establish subsurface conditions. All borings should extend at least 2 feet below the expected depth of removal of material unless consolidated material that is not suitable for use is encountered.

Usually about 12 borrow-area test holes will suffice for all but the larger structures, but local topography, geology, and ground-water conditions may require great variation in the intensity of this study.

Reservoir-basin test holes.--Local geologic conditions may require subsurface exploratory work in the general area of the site and reservoir.

The location, number, and depth of these test holes depends on the specific problem to be solved. If the presence of cavernous or permeable strata that may adversely influence the functioning or stability of the structure is suspected, it is necessary to put down enough test holes to determine these conditions in order to develop appropriate safeguards.

<u>Foundation-drain and relief-well test holes</u>.--If exploration along the centerline of the proposed dam shows the presence of permeable materials, consideration should be given to the possible need for foundation drains, relief wells, or both.

Relief wells are usually located at or near the downstream toe of a dam. Foundation drains may be located anywhere between the centerline and the downstream toe, depending on the specific problems and conditions. Either foundation-drainage method, or both, may be necessary to control uplift pressure, to facilitate consolidation, or to prevent piping. In many cases deep foundation drains, consisting of trenches backfilled with properly designed filter materials can be used as an economical alternate for relief wells. This method is suited to many stratified or lenticular materials and to those situations where confined aquifers can be tapped feasibly by excavation.

The design engineer is responsible for determining the kind and location of drainage system to be used. The geologist must recognize the problem, however, and anticipate possible solutions in order to get sufficient information for design.

Exploration must be carried downstream from the centerline to determine the extent and continuity of permeable substrata where foundation drains may be needed. A series of accurately logged borings in the vicinity of the downstream toe, together with centerline information, usually provides enough data for design of the drainage system. Where foundation conditions are highly variable, additional test holes may be needed between the centerline and the downstream toe.

<u>Stream-channel test holes</u>.--If the stream channel contains boulders, roots, debris, and organic matter that cause poor foundation conditions, it may be necessary to remove these materials from beneath the dam as "special stream-channel excavation." Usually, excavation is required from the upstream toe of the dam to a point two-thirds of the distance from the centerline to the downstream toe to prevent leakage through the foundation. Channel investigations provide information on the depth, nature, quantity, and location of the deposits that are to be removed. Sufficient exploration should be made to determine this. If possible, one test hole should be located in the bottom of the channel. Space test holes in stream channels so that the volume of material to be excavated can be estimated closely.

The stream channel may be the best local source of sand or gravel for use in foundation drains, filter blankets, and roadways. The geologist should carefully log and sample these materials, and if they seem to be suitable for these purposes, indicate the need for washing and screening.

Other investigations.--Test holes may be needed at other locations in the general site area. It may be necessary to determine the continuity of materials upstream and downstream throughout the foundation and reservoir area. Information on the depth, nature, quantity, location, and extent of undesirable deposits such as organic soils, very soft silts and clays, and boulders within the foundation area may be needed. Structural features such as faults and contacts may have to be accurately located and their attitude determined through the site area. There may be geologic conditions that require additional subsurface exploration in order to adequately evaluate their effect on the design, construction, and operation of the proposed structure.

## Subsurface Exploration. Phase 2: Obtaining Samples

### Purpose and Objectives

Some types of samplers used for logging in phase 1 furnish small disturbed samples that are adequate for laboratory testing; others do not. The purpose of phase 2 of the detailed subsurface investigation is to obtain the necessary undisturbed samples and the larger or additional small disturbed samples of unconsolidated materials that are required for soil mechanics testing and analysis.

In phase 1 test holes were bored and logged and various field tests carried out. These data were analyzed and interpreted geologically, and geologic profiles and cross sections were prepared. From a study of these profiles and cross sections and the results of field tests the engineer and the geologist determined what horizons should be sampled and the type, size, and number of samples needed.

The minimum requirements for sampling are outlined by group classification in chapter 5. Sample requirements based on the character of materials and on the tests desired are given in chapter 3. Sampling methods and equipment depend on the character and condition of the material and on the type and size of sample needed (chapter 2).

Holes bored to get undisturbed samples of unconsolidated materials are usually of a larger diameter than those bored for logging. For some situations a different drilling rig from that used in phase 1 must be used or this phase of the investigation must be done by contract, even though SCS-owned equipment was used for logging. The objective is to select locations for these holes so that the required number, size, and type of samples can be obtained with a minimum amount of boring.

### Numbering and Locating Sample Holes

Locate sample holes adjacent to the test holes that were bored and logged in phase 1. In this way the depth at which the sample is to be taken can be determined accurately to insure that it represents the selected horizon.

These holes are not logged, and they are given the same Nos. as the logged holes to which they are adjacent. They are not plotted separately on the plans and profiles, but the symbol for the like-numbered logged holes on the plan is changed from a dot to a circled dot and the sampled segment is delineated on the graphic log.

## Investigation of Ground Water

Ground-water conditions may influence the design, construction, and operation of a dam. Where the surface of the underground water (water table) is at or near the ground surface, special design features may be needed to insure stability. In addition special construction procedures may be needed. This condition may eliminate some areas from consideration as a source of borrow material. Where the water table is very low, getting adequate supplies of water to use in construction may be a problem. Artesian water (ground water under enough pressure to rise above the level at which it is reached in a well) may also create special problems.

Impounding water, even temporarily, may modify ground-water conditions. New springs may be created, the flow of springs within the reservoir area may be reversed and they may emerge at a new location, and unsaturated rock or soil materials may become saturated. Other changes in the location and movement of underground water may occur. Frequently, such effects of the structure must be considered before its construction.

### Purpose and Objective

The purpose of ground-water studies in dam-site investigations is twofold: (1) To determine present ground-water conditions that may affect the design, construction, and operation of the proposed structure; (2) to determine and evaluate the geologic conditions that may influence the effect of impoundage on ground water.

The objective is to furnish the engineer (1) an analysis of ground-water conditions and (2) an interpretation of the geologic conditions that may influence the effect of impoundage on the location and movement of underground water. This enables him to give due consideration to these problems in planning and in the design and construction of the structure.

### Procedure

Examine springs and seeps in the vicinity of the structural site and reservoir area and record their elevation. Where necessary for analysis, prepare a map that shows the location and elevation of springs and seeps. Record any information on source of the water, volume of flow, whether flow is perennial or seasonal, and location of the recharge area. For all test holes that extend below the water table record the elevation of the water table and plot it on the geologic cross sections and profiles. If necessary, prepare a water-table contour map. Record any information on seasonal fluctuation of the water table and note the source of this information. Wait 1 day or longer after drilling to measure the water level in test holes to allow time for stabilization of the water level. Log all artesian aquifers and record any information on the hydrostatic-pressure level and volume of flow. Draw a contour map of the piezometric surface if it is needed.

Locate any permeable materials in the foundation, abutment, and reservoir areas and determine their thickness, elevation, and continuity. Where permeability is a critical factor, obtain values for the coefficient of permeability either by field tests or by laboratory tests on undisturbed samples.

The following field tests are helpful in ground-water investigations.

1. Use of indicators to trace ground-water flow. Water-soluble organic dyes such as sodium fluorescein have been used successfully in many instances.
2. Pressure tests to locate permeable horizons.
3. Pumping-in tests to determine the value of the coefficient of permeability.
4. Use of piezometers.
5. Pumping-out tests.

If local sources of water are adequate for construction purposes but there is some question about the quality of the water, take samples for chemical analysis.

## Report of Detailed Geologic Investigation

### Narrative Report

In reporting the geologic conditions of a structural site, be as brief and concise as possible but describe all geologic problems thoroughly. Prepare the report in narrative form or use the standard reporting forms, SCS-376A and SCS-376B.

The report must set forth clearly the methods of investigation and the information obtained. Include copies of all field logs in the report.

Prepare a supplement to the report that contains interpretations and conclusions and label it "For In-Service Use Only." This supplement can be prepared on form SCS-376C. Copies of completed plan and profile sheets for geologic investigations must accompany the report supplement.

The following outline can be used in preparing the narrative report.

I. Introduction.
  A. General.
    1. Date of exploration.
    2. Personnel engaged in exploration.
    3. Watershed (name and location).
    4. Site No.
    5. Site group and structure class.
    6. Location.
    7. Equipment used (type, size, makes, models, etc.).
    8. Site data.
      a. Size of drainage area above site (square miles and acres).
      b. Maximum pool depth.

(1) Sediment pool.
(2) Flood pool.
(3) Other pools.
c. Dam.
(1) Maximum height.
(2) Length.
(3) Location of spillway.
(4) Volume of fill.
9. Special methods used.
B. Surface geology and physiography.
1. Physiographic area.
2. Topography.
a. Steepness of valley slopes.
b. Width of flood plain.
3. Geologic formations and surficial deposits.
a. Names and ages (e.g., Jordan member, Trempealeau formation, Cambrian age; Illinoian till; Recent alluvium).
b. Description.
c. Topographic position.
4. Structure.
a. Regional and local dip and strike.
b. Faults, joints, unconformities, etc.
5. Evidence of landslides, seepage, springs, etc.
6. Sediment and erosion.
a. Gross erosion, present and future, by source.
b. Delivery rates.
c. Sediment yield.
d. Storage requirements and distribution.
7. Downstream-channel stability.
a. Present channel conditions.
b. Anticipated effect of the proposed structure.

II. Subsurface geology.
A. Embankment foundation.
1. Location and types of test holes and number of samples of each type collected.
2. Depth, thickness, and description of pervious or low-volume-weight strata. Give detailed data on aquifers or water-bearing zones.
3. Depth and description of firm foundation materials.
4. Location, depth, thickness, and description of any questionable materials.
5. Description of abutment materials, including depth and thickness of pervious layers or aquifers.
6. Location, attitude, pattern, and other pertinent data on any geologic structural features such as joints, bedding planes, faults, and schistosity.
7. Location of water table and estimated rate of recharge (high, medium, low).
8. Permeability of abutments.
B. Centerline of outlet structure.
1. Location and type of test holes and number of samples of each type collected.

2. Depth, thickness, and description of pervious or low-volume-weight strata.
3. Depth and description of firm foundation materials.
4. Location, depth, thickness, and description of any questionable materials.
5. Location, attitude, pattern, and other pertinent data on any geologic structural features such as joints, bedding planes, faults, and schistosity.
6. Location of water table and estimated rate of recharge (high, medium, low).

C. Emergency or other open spillway.
1. Location and types of test holes and number of samples of each type collected.
2. Location, depth, thickness, and description of materials encountered, including
   a. Hard rock or unconsolidated material to be removed and estimated volume of each.
   b. Material at base of excavation.
   c. Any questionable material.

D. Borrow area(s).
1. Location of test holes and number and type of samples collected.
2. Location, depth, thickness, description, and estimated quantities of various types of material.

E. Relief-well and foundation-drain explorations.
1. Location of test holes and number and type of samples collected.
2. Description of materials, including location, depth, thickness, and description of pervious strata.

F. Other explorations.
1. Purpose.
2. Location of test holes and number and types of samples collected.
3. Description of materials.

G. Water supply.
1. Available sources (farm ponds, rivers, wells, municipal, etc.) and quantity.
2. Quality of available water. If questionable, what samples were taken for analysis.

H. Construction materials (other than earthfill).
1. Sources of materials for concrete aggregate, riprap, impervious blanket, wells, and drains.
2. Description, location, and estimated quantities of materials available.

III. Logs.
Attach completed copies of form SCS-533.

IV. Interpretations and conclusions (for in-Service use).

A. Interpretations.
1. Interpretations of geologic conditions at the site.
2. Possible relation of conditions to design, construction, and operation of structure.

B. Conclusions.
Geologic conditions that require special consideration in design and construction.

C. Attach completed copies of forms SCS-35A, -35B, and -35C.

Report Supplement for In-Service Use Only

Record only basic data and facts in the geologic report. On request, this report is made available for inspection by non-SCS interests. Report separately interpretations, conclusions, and suggestions and label this supplementary report "For in-Service use only" to restrict its use.

From the surface geology and the facts obtained by underground exploration the geologist should interpret geologic conditions at the site and their possible relation to the suitability of the site and to the design, construction, and operation of the proposed structure. Specifically, he should point out any problems likely to result from the geologic conditions, such as foundation weakness, seepage problems, excess ground water during construction, difficulties of excavation, spillway problems, or problems concerning available borrow materials.

The geologist should make recommendations on possible means and methods of overcoming problems that result from the geologic conditions. He should indicate the most efficient use of available materials and of the geologic features of the site. His recommendations might include suggestions to the design engineer on such items as location of the principal spillway, location of the emergency spillway, depth of core trench, and depth of keyways into abutments. He should indicate the need for an impervious blanket, grouting, or other control of excessive water loss. He should point out any special problems that may arise during construction of the dam such as problems of excavation and suitability of the excavated rock for use as riprap, sources of concrete aggregate, and recommendations on sources of water for construction.

Distribution of Geologic Report

Send copies of the geologic report and supplement, including the field logs and completed "Plan and Profiles for Geologic Investigation," to:

1. The EWP Unit geologist for all sites for structures requiring EWP Unit review or approval of the engineering plans.
2. The soil mechanics laboratory to which samples are sent.
3. A copy must accompany the design data, and additional copies are to be distributed as directed by the State Conservationist.

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