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	Engineering and Design GEOTECHNICAL INVESTIGATIONS	
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DEPARTMENT OF THE ARMY
U. S. Army Corps of Engineers
Washington, D. C. 20314

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Engineer Manual
No. 1110-1-1804

29 February 1984

Engineering and Design
GEOTECHNICAL INVESTIGATIONS

1. Purpose. This manual establishes criteria and presents guidance for geotechnical investigations during the various stages of development for civil and military projects.

2. Applicability. This manual applies to all field operating activities having military and civil works responsibilities.

3. Discussion. Geotechnical investigations are made to determine those geologic, seismologic, and soils conditions that affect the safety, cost effectiveness, and design of a proposed engineering project. Insufficient geotechnical investigations, faulty interpretation of results, or failure to portray results in a clearly understandable manner have contributed to costly construction changes and post-construction remedial work and could be the cause of failure of a structure.

FOR THE COMMANDER:

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This manual supersedes EM 1110-1-1801, 1 November 1960, and EM 1110-2-1803, March 1954.

CHAPTER 1
INTRODUCTION

1-1. Purpose. This manual establishes criteria and presents guidance for geotechnical investigations during the various stages of development for civil and military projects. The manual is intended to be a guide for use in planning geotechnical investigations and not a textbook on engineering geology and soils exploration. Actual investigations in all instances must be tailored to the individual projects. Geotechnical investigations for roads and airfields are not discussed.

1-2. Applicability. This manual applies to all Corps of Engineers field operating activities.

1-3. References. Standard references pertaining to this manual are listed in Appendix A, References and Bibliography. Each reference is identified in the text by the designated Government publication number or performing agency. Additional reading materials are listed in the Bibliography and are indicated throughout the manual by numbers (item 1, 2, etc.) that correspond to similarly numbered items in Appendix A.

1-4. Rescission. This manual supersedes EM 1110-1-1801, "Geologic Investigations" and EM 1110-2-1803, "Subsurface Investigations, Soils."

1-5. Background. Geotechnical investigations are made to determine those geologic, seismologic, and soils conditions that affect the safety, cost effectiveness, and design of a proposed engineering project. Insufficient geotechnical investigations, faulty interpretation of results, or failure to portray results in a clearly understandable manner have contributed to costly construction changes and postconstruction remedial work and could be the cause of failure of a structure. The investigations are performed to determine the geologic setting of the project; the geologic, seismologic, and soil conditions that influence selection of the project site; the characteristics of the foundation soils and rocks; all geotechnical conditions which influence project safety, design, and construction; and sources of construction materials. A close relationship exists between the geologic sciences and other physical sciences used in the determination of project environmental impact and mitigation of that impact. Those individuals performing geotechnical investigations are among the first to assess the physical setting of a project. They have a responsibility to observe and report potential conditions relating to environmental impact. The methods employed for geotechnical investigations and the magnitude of the investigations depend on the size of the project, type of structure, and the complexity of regional and local geotechnical conditions.

1-6. Scope of Manual. The manual establishes the scope of geotechnical investigations for the various planning, design, and construction stages of civil and military projects and provides criteria and guidance on investigation methods. Chapter 2 provides guidance on the scope of geotechnical investigations appropriate to various stages of project development. The conduct of initial, regionally oriented geotechnical investigations is contained in Chapter 3, while Chapter 4 provides guidance on the conduct of field investigations. Chapter 5 provides guidance on laboratory investigations. Appendices cover details for geologic mapping of construction areas and examples of drilling logs. Guidance is in general terms where methodologies are described in available references. Where descriptions are otherwise unavailable, they are provided herein.

CHAPTER 2
SCOPE OF INVESTIGATIONS

2-1. General. From project conception through construction, geotechnical investigations are sequenced to provide the level of information appropriate to the particular project development stage. This sequence is shown on table 2-1. In most instances, initial geotechnical

Table 2-1. Sequence of Geotechnical Investigations with Project Development Stages

Project Development Stages		
Military Construction	Civil Works	Geotechnical Investigations
Preconstruction and site selection studies	Feasibility studies	Development of regional geology Field reconnaissances and initial field investigations
Final design studies	Preconstruction planning and engineering General Design Memorandum and feature design memoranda	Review of regional geology Site selection investigations Foundation and design investigations
Construction	Construction	Constructibility review, quality assurance, and postconstruction documentation activities

investigation will be general and will cover large geographic areas. As project development continues, the geotechnical investigations become more detailed and cover smaller areas. Ultimately, the geotechnical investigation can involve highly detailed geologic mapping such as a rock surface for a structure foundation. The scope of the various increments of investigation are described in the following paragraphs. Although some material is presented in detail, rigid adherence to an inflexible program is not intended. It is the responsibility of the geotechnical personnel in the field operating activities to design individual geotechnical investigations to the particular project requirements and local conditions. However, there are minimum requirements for geotechnical investigations to be performed as part of the project development stages.

Section I. Civil Works Projects

2-2. Feasibility Studies.

a. Purpose. Feasibility studies are made to determine the environmental, economic, and engineering feasibility of the recommended project. Planning guidelines for conducting these studies are contained in ER 1105-2-10. Guidelines on engineering activities during feasibility and preconstruction planning and engineering studies are provided in the 1110 series of publications.

b. Scope of Geotechnical Investigations. Geotechnical investigations during planning studies should be performed to a level which assures the comparability of alternate plans presented in the feasibility study report. These investigations should be sufficiently complete to permit selection of the most favorable site areas within the regional physical setting, determine the general type of structures best suited to the site conditions, assess the geotechnical aspects of environmental impact, and to ascertain closely the costs of developing the various project plans.

c. Investigation Steps. Planning study geotechnical investigations are generally performed in two parts--development of regional geology and initial field investigations. The development of regional geology will be initiated during the early stages of the study. Initial field investigations will be started after the regional studies are sufficiently detailed to indicate localized areas requiring geotechnical clarification.

(1) Development of Regional Geology. Figure 2-1 is a schematic showing the steps involved and data needed in the development of regional geology. Knowledge of the regional geology is essential to preliminary planning and selection of sites and to interpretation of subsurface exploration data. With the exception of fault evaluation studies, the determination of seismicity and preliminary selection of the design earthquake is performed in conjunction with the development of the regional geology. Much of the data needed for describing the regional geology and for determining seismicity is identical and the efforts can be combined. The engineering seismology requirement for more in-depth studies of tectonic history, historical earthquake activity, and location of possible active faults is a logical extension of the regional geologic studies. Requirements for the conduct of the earthquake design and analysis, including geological and seismological studies, are contained in ER 1110-2-1806. The compiled and properly interpreted regional geologic and field reconnaissance information should be used to postulate a geologic model for each site. This model, which will be revised during successive investigation stages, will provide the information necessary to determine the scope of initial

CIVIL WORKS FEASIBILITY STUDIES

GEOTECHNICAL INVESTIGATIONS

DEVELOPMENT OF REGIONAL GEOLOGY

DATA COLLECTION

INTERAGENCY COORDINATION AND COOPERATION

Sources of geologic, hydrologic and soils data; insight into geologic hazards; seismicity; construction materials; experiences of others.

SURVEY OF AVAILABLE INFORMATION

Information similar to that obtained in interagency coordination; published data on material properties; geologic history; ground water studies.

MAP STUDIES

Formation descriptions and contacts; soil types and locations; gross structure, fault locations; landforms, drainage, slopes, landslides; locations of springs, quarries, etc.

REMOTE SENSING STUDIES

Landforms; drainage; linears; soil and rock type boundaries; outcrops; seeps; sinkholes; slopes; erosion features; vegetation.

FIELD RECONNAISSANCES

Ground truth for remote sensing; outcrop descriptions; site terrain; soil depths and descriptions; springs; possible structure locations; observable structure, bedding, and joints.

DATA ANALYSIS

DISTRIBUTION OF ROCK TYPES

Transition from time-stratigraphic units to groupings of rock materials by physical characteristics.

DISTRIBUTION OF SOIL TYPES

Equate geologic/soil survey nomenclature to engineering nomenclature.

GEOLOGIC STRUCTURE

Establish spatial location of rock materials; locate major structural features; determine probable distribution of more detailed structural and textural features.

GEOLOGIC HISTORY

Genesis of rock types; relationship to significant properties; overburden depositional processes, relationship to properties and preconsolidation history.

SEISMICITY

Historical seismicity; locations and characteristics of probable capable faults; possible earthquake magnitudes in region; possible intensities at candidate sites; preliminary selection of ground motions at candidate sites.

HYDROGEOLOGY

Regional ground water picture; general hydraulic characteristics of subsurface materials; probable ground water and seepage conditions at candidate sites; preliminary assessment of project impact on ground water.

CONSTRUCTION MATERIALS

Existing sources in region located; probable areas for development rock and soil borrow delineated.

Regional geologic and soils conditions established; preliminary assessments of seismicity and construction materials; tentative models of geologic conditions at potential sites developed; input for Environmental Impact Statement (EIS) developed.

Figure 2-1. Schematic diagram of development of regional geology field investigations. Procedural information on the steps required to develop the regional geology and perform field reconnaissances is contained in Chapter 3.

(2) Initial Field Investigations. Figure 2-2 details the general areas and subitems for the initial field investigations. Areal extent of the investigations is determined by the size and nature of the project; however, each site investigation should be complete. Procedural information on the methods for making a field investigation are presented in Chapter 4. Major projects, such as dams and reservoirs, powerhouses, and locks and dams, require comprehensive field investigations. Areal and site geotechnical mapping allows early modification of developed geologic models and tentative layouts for surface geophysical surveys and subsurface explorations. Properly conducted surface geophysical surveys can provide information over relatively large areas on overburden depths, depth to the water table, and geologic contacts. Such surveys, prior to exploration drilling, can reduce the number of borings in proposed structure foundation areas, and in some cases, the number of borrow area borings. The surveys should be run along axes of potential damsites and along canal alinements; at lock, off-channel spillway, and tunnel and conduit sites; at potential borrow and quarry sites; and at locations where buried channels, caverns, or other elusive and important geologic conditions are suspected. Exploratory drilling is required at all site areas to be reported in the feasibility study. The numbers and depths of borings required to provide adequate coverage cannot be arbitrarily predetermined but should be sufficient to reasonably define the subsurface in the various site areas. Investigations necessary for levees, floodwalls, pumping plants, recreation areas, and other miscellaneous structures are not as extensive as those required for major structures and projects. Generally, the scope of the regional geologic study is much reduced as the projects are usually authorized for site-specific reasons and the field investigation program should be tailored to specific site needs. Field investigations in connection with planning of channel improvements or diversion channels should be sufficient to determine the types of materials to be excavated, the stability of bank slopes, and the susceptibility of the material to scour. In the case of irrigation or perched canals, seepage losses may be a significant problem. The field investigations should examine the possible need for an impervious lining and the availability of material for this purpose. Coastal engineering studies present a unique opportunity to blend the best features of remote sensing with site characterization studies. Remote sensing can be a valuable tool in determining coastal geomorphic characteristics, geologic structure, sediment sources and transport directions, and the chronological changes in erosion cycles. The areal studies thus provide the necessary data to make economical and efficient site characterization studies using, as appropriate, barge or platform mounted drill equipment, standard and specialized sampling devices such as the vibracore, subbottom profiler and scanner, and mineralogic analysis of index minerals.

CIVIL WORKS FEASIBILITY STUDIES

GEOTECHNICAL INVESTIGATIONS

INITIAL FIELD INVESTIGATIONS

DATA COLLECTION

AREAL AND SITE GEOTECHNICAL MAPPING

Distribution of surface materials; structure; relation between materials and geomorphic expression; tentative locations for geophysical and/or subsurface explorations.

SURFACE GEOPHYSICAL SURVEYS

Distribution of distinguishable subsurface materials at potential structure sites and rock and/or soil borrow areas; depth to water table; preliminary data on elastic and electrical properties; concept concerning homogeneity of subsurface.

SUBSURFACE EXPLORATIONS

Control borings at potential structure sites and rock and/or soil borrow areas; borehole logs; index tests on representative rock and soil samples; in situ hydraulic tests, camera or TV surveys; downhole geophysical logs.

DATA ANALYSIS

AREAL CONDITIONS

Develop map of project area (e.g. reservoir area); describe possible material sources, material types, properties, amounts; determine unusual or safety related geologic conditions, faults, landslides, sinkholes, solution susceptible materials, etc.; update and expand hydrogeologic analyses including impact on ground water.

SITE CONDITIONS

Correlate surface and subsurface data at potential sites; develop geologic map and sections for each site; assess structural and textural data for materials; assess results of index tests; develop preliminary assessment of rock and soil foundation conditions; delineate conditions affecting choice of structure for each site.

Areal geologic and soils conditions developed; geologic, soils, and engineering conditions at sites associated with each plan developed to a level necessary to assure each plan is a viable, safe, complete technical system; geologic models at proposed sites upgraded; level of geotechnical investigations necessary to accomplish design established; need for dynamic analyses tentatively determined; EIS input updated.

Figure 2.2 Schematic diagram of initial field investigations

d. Reporting for Feasibility Studies. The reporting of results from feasibility study investigations will be in accordance with the overall study reporting requirements contained in ER 1105-2-60, Planning Reports. The results of all geotechnical investigations performed as part of the planning study efforts will be presented in detail in the appropriate report. Sufficient relevant information on the regional and considered site geotechnical conditions must be presented to support the rationale for plan selection, the project safety and environmental assessments, the preliminary project design and cost estimates, and geotechnically related conclusions and recommendations. This information should be presented in summary form in the study report and in sufficient detail in appendices to allow evaluation and review.

(1) The study report should contain summaries of the regional geologic, soils, and seismological conditions plus brief summaries of the areal and site geotechnical conditions for each detailed plan. These summaries should include: local topography, thickness and engineering character of overburden soils, description of rock types, geologic structure, rock weathering, local groundwater conditions, special foundation conditions such as excavation or dewatering problems, low strength foundations, cavernous foundation rock, etc., possible reservoir rim problems (dam and reservoir projects), description of possible borrow areas and quarries, and accessibility of sources of construction materials. The summaries should conclude with a discussion of the relative geotechnical merits of each plan.

(2) Discussions of the regional geology and initial field investigations should be presented in an appendix on engineering investigations. The content of the discussion on regional geology should include the items on Figure 2-1. In addition, a discussion of topography should be included. Drawings should be used to explain and augment the detailed discussion of regional geology. As a minimum, the drawings should include a regional geology map, regional geologic sections showing the spatial relationship of rock units and major geologic structures, a regional lineament map, and a map of recorded and observed seismic events (epicenter map). Because summaries of areal and site geotechnical conditions for each detailed plan will be included in the study report, the detailed discussion of areal and site geology, foundation conditions and problems presented in the appendix may be limited to the recommended detailed plan. Figure 2-2 contains much of the information which should be included in the detailed discussion of areal and site geotechnical conditions. This discussion should indicate the sources from which information was obtained and will include the following items:

Investigations performed
Areal and site geology (including topography of site or sites)

Engineering characteristics of soil, rock, foundation, and reservoir conditions
Mineral deposits
Borrow and quarry sites
Construction materials
Conclusions and recommendations
Graphics

2-3. General Design Memorandum Studies.

a. Purpose. General Design Memorandum studies (GDM) are initiated generally after a Planning Feasibility Study has been completed. GDM studies are developed to reaffirm the basic planning decisions made in the feasibility study, establish or reformulate the scope of the project based on current criteria and costs, and formulate the design memoranda which will provide the basis for the preparation of plans and specifications. Figure 2-3 schematically outlines the engineering tasks for the GDM studies with the requirements for geotechnical information.

b. Scope of Geotechnical Investigations. Geotechnical investigations performed during the GDM studies should be in sufficient detail to assure that the authorized measures can be implemented. The emphasis is toward site-specific studies which will provide the detail and depth of information necessary to select the most suitable site and structures to achieve project goals. The studies are performed in a series of incremental steps of increasing complexity beginning with the Site Selection study on major projects to the feature design studies. Geotechnical procedures for performing field and laboratory investigations for these studies are found in Chapters 4 and 5, respectively.

c. Site Selection Study. As implied by its title, this study serves to select the specific site at which the authorized project will be developed. The study should consist of those observations and investigations necessary to support the decision to select one site and abandon the alternate sites.

(1) Preliminary. The initial phase should start with a comprehensive review of all geotechnical studies made during the planning study period. If there is a significant gap in time between the feasibility and GDM studies, considerable geotechnical information may have been collected and published by federal and state geotechnical agencies in the study area. This data should be obtained and correlated with the completed studies for evidence of significant changes in the geological knowledge of the study region. This is particularly important in the disciplines of seismology and hydrogeology.

(2) Data Collection. In the case of major projects such as dams, powerhouses, and navigation structures, some latitude normally exists in

CIVIL WORKS GENERAL DESIGN MEMORANDUM STUDIES

GEOTECHNICAL INVESTIGATIONS

PURPOSE AND SCOPE

Perform all engineering and design and reporting for the authorized plan. Serve as a basis for the preparation of construction plans and specifications. Primarily concerned with the functional and technical design of structures necessary to achieve project objectives and with the development of plans and specifications.

TASKS

- Develop engineering details of approved project plan.
- Update cost and benefit estimates.
- Provide basis for cost sharing agreements, preparation of plans and specs, acquisition of lands, and negotiation of relocation agreements.
- Establish design and operating requirements to insure safe functional project.
- Facilitate orderly scheduling and programming of funds for detailed design and construction.
- Continue environmental assessment based on required additional studies identified in the draft EIS.
- Provide the basis for the District Engineer's recommendations.

Sufficient geologic and soils information to verify project plan, axis selection, types of structures, estimates of costs, and to support the project purpose.

Field investigations, lab analyses, design computations to determine adequacy and use of materials, strengths, slopes and protection of critical sections of embankments and foundations.

Foundation investigations, hydraulic design studies and cofferdam design studies to determine most economical water control plan.

Describe sources and indicate suitability of concrete aggregate, cement, earth and rock borrow materials.

Investigations and laboratory analyses and typical design computations to determine source, adequacy and use of construction materials.

Field investigations, analyses, and views of owners of relocations.

Plans for reading and evaluating instrument data and making visual inspections of dams and downstream areas, both related to pool level.

Proposed instrumentation.

Figure 2-3. Outline of General Design Memorandum studies the proposed locations of the structures. At this stage possible structure sites that would serve the intended project purposes should be evaluated before selecting a field investigations program. Geologic and hydraulic information collected during the feasibility study is generally sufficient for this purpose. After the obviously poor sites have been eliminated, a field investigation program should be developed. The type of data and collection methodology are outlined schematically in figure 2-4. The investigation program should emphasize the completion of surface geologic mapping, expansion of surface geophysical surveys, and broadening the scope of groundwater investigations. Sufficient borings should be made at each potential site so that correlation of surface mapping and geophysical surveys is reasonably accurate. Use of the cone penetrometer test method as part of a subsurface investigation program should be evaluated where geologic conditions are appropriate for this and subsequently more complex site studies. Subsurface sampling should be comprehensive to the point where laboratory indexing of engineering properties of soils and rock types, where appropriate, can be accomplished. Earthquake engineering analyses should be made if the seismicity studies made during the feasibility study indicate their need. At this time a preliminary seismic evaluation should be made of the proposed structures, and trenching performed if local active faulting is identified. The end result should be that areal and site geotechnical conditions are defined to the extent necessary to support design studies needed for reliable cost estimates. Data on proposed sites should be sufficiently complete to fully consider the effect of geotechnical conditions on site selection.

(3) Reporting Site Selection Studies. The reporting of results of site selection studies will be in accordance with ER 1110-2-1150. The site selection design memorandum may be a separate document prepared prior to the GDM for complex projects, or may be submitted as a major appendix to the GDM. The content of the Site Selection Memorandum will include the items shown in figure 2-4. The discussions will be augmented by geologic maps and profiles, borings, laboratory and geophysical data all presented at a readable scale. The recommended site must be validated by sufficient geotechnical information in light of current conditions and criteria so that reformulation of the project due to geotechnical problems will not be necessary during the GDM studies.

d. Design Investigations. All engineering and design, and reporting for the selected plan are performed during this phase of the investigation. The studies are concerned primarily with the functional and technical design of structures necessary to achieve project objectives and with the development of plans and specifications. Design investigation tasks are outlined schematically in figure 2-5 and are discussed as follows.

CIVIL WORKS GENERAL DESIGN MEMORANDUM STUDIES

GEOTECHNICAL INVESTIGATIONS

SITE SELECTION INVESTIGATIONS

DATA COLLECTION

AREAL AND SITE GEOTECHNICAL MAPPING

Review survey study maps; update or prepare new area and site maps for each candidate site.

Distribution of surface materials; outcrop locations; rock structure; springs; slope conditions; potential hazards.

GROUND WATER DATA

Review survey study data; update or initiate compilation of water well and other piezometric data; determine needed additional data, initiate collection.

SURFACE GEOPHYSICAL SURVEYS

Review survey study data and analysis; if feasible expand surveys to provide subsurface material contacts for foundations and material sources at candidate sites; where needed, initiate special surveys (e.g. to obtain dynamic elastic constants or void detection).

SUBSURFACE EXPLORATIONS

Expand from prior drilling to provide adequate foundations and materials sources explorations at candidate sites.

Log soil and rock types, rock structure and drilling conditions; water pressure or pumping tests; borehole photography and/or TV surveys; in-hole geophysical surveys for correlation and, where needed for special properties.

TRENCHING

If and where needed for determination of fault activity.

SAMPLE TESTING

Classification and index tests on foundation and borrow materials; preliminary special tests where needed (e.g. dynamic analyses, etc.)

DATA ANALYSIS

AREAL CONDITIONS

Compile final geologic map of project area (e.g. reservoir area); show all pertinent geologic and soils conditions (e.g. landslides, sinkholes, potential reservoir leakage locations, etc.); locate mineral sources, develop geologic profiles.

SITE CONDITIONS

Compile detailed geology map for each site; develop geologic sections; classify soils; describe rock types; show rock structure and fracturing; describe ground water conditions and hydraulic characteristics of materials; describe rock weathering; discuss pertinent soil and rock engineering properties.

GROUND WATER CONDITIONS

Determine extent and mode of project induced changes in ground water regime; show predicted changes for acquifers; discuss predicted impact on water supplies and water-sensitive habitats.

EARTHQUAKE ANALYSES

Where prior seismicity studies indicate, determine design earthquakes for each site; perform preliminary dynamic analyses; evaluate foundation areas for potential fault movement.

CONSTRUCTION MATERIALS

Locate and describe proposed borrow and/or quarry sites; determine available volumes of materials, depths of burden; describe properties; make preliminary assessment of commercial sources.

MINERAL AND OTHER RESOURCES

Determine location and extent of mineral and other resources which may be impacted by project (e.g. paleontological, archeological, etc.)

Project areal and site geotechnical conditions defined to extent necessary to support design studies needed for reliable cost estimates. Data on candidate sites is sufficiently complete to fully consider effect of geotechnical conditions on site selection. All environmental conditions and estimated impacts are up to date.

Figure 2-4. Schematic diagram on development of site selection investigations, GDM

CIVIL WORKS GENERAL DESIGN MEMORANDUM STUDIES

GEOTECHNICAL INVESTIGATIONS

DESIGN INVESTIGATIONS

DATA COLLECTION

ENVIRONMENTAL/GROUND WATER DATA

Continue needed ground water data collection in the form of observation well readings, pump tests and etc. Collect any geotechnical data required to update environmental assessments.

SUBSURFACE EXPLORATIONS, EXCAVATION/STRUCTURE SITES, MATERIALS SOURCES AND RELOCATIONS

Expand coverage from Site Selection Program.

Log soil and rock types, rock structure and drilling conditions.

BOREHOLE PHOTOGRAPHY AND/OR TV

Obtain fracture frequency, orientation, and aperture; macrotextural and structural features; boring wall condition.

BOREHOLE GEOPHYSICS

Expand coverage with noncore borings.

Obtain in situ properties and stratigraphic correlation.

WATER PRESSURE AND/OR PUMPING TESTS

Obtain permeabilities; monitor water levels.

MATERIAL TESTING

Includes classification, index, and engineering behavior tests; also complete special testing initiated in earlier programs.

EXPLORATORY EXCAVATIONS AND CONSTRUCTIONS

Trenches, pits, adits, calyx holes, test quarries or borrows, test fills, abutment stripping, test grout panels, and etc.; in situ examination, in situ materials properties tests.

INSTRUMENTATION

Install and initiate readings on foundation instrumentation (e.g. piezometers, slope indicators, etc.) to develop base or background levels.

DATA ANALYSIS

GROUND WATER CONDITIONS/ASSESSMENT

Continue analyses initiated in earlier program; formulate statement of project impact on ground water.

PROJECT SITE CONDITIONS

Update site geologic maps, geologic sections, rock and soil classifications, rock structure, material hydraulic characteristics, ground water conditions; complete design earthquake, reservoir leakage, and other special studies.

STRUCTURE/EXCAVATION SITE CONDITIONS

Develop detailed distribution of subsurface materials, select pertinent engineering properties for each material; complete any dynamic analyses; analyze data and describe encountered conditions from any test excavations, quarries, grout programs, etc.; discuss all conditions effecting design decisions.

CONSTRUCTION MATERIALS

Finalize volume estimates; show distribution of subsurface materials and their properties; analyze and describe results from test fills; finalize assessment of commercial materials sources.

INSTRUMENTATION

Reduce data from various sources, correlate data with any events occurring, produce baseline plots for construction/postconstruction conditions.

RELOCATIONS

Develop pertinent data for each relocation increment in the same manner as structure/excavation sites.

Geotechnical conditions developed in sufficient detail to establish final design and operating requirements for a safe, functional project, develop design details, prepare final cost estimates, prepare plans and specifications, negotiate relocation agreements, acquire necessary lands, and complete environmental assessments.

Figure 2-5. Schematic diagram for design investigations for GDM studies

(1) Preliminary. Upon commencement of the design investigations (post-site selection), all regional and site-specific geotechnical data should be reviewed before commencement of field investigations. New data, particularly that generated by other agencies, both federal and state, should be obtained and incorporated into the original data base.

(2) Data Collection. The foundation and design data collection activities are iterative, developing greater detail as the project design progresses toward the preparation of plans and specifications.

(a) GDM Data Collection. In general, a closer order of subsurface investigations is used in site selection studies. Where soils strongly influence the foundation design, undisturbed soil sampling should be initiated or expanded in order to classify and index their engineering properties in more comprehensive detail. Rock types and conditions, geologic structure, and engineering properties should be defined to the extent necessary to design foundation treatment. In the case of water retention structures, pump and/or pressure tests should be performed. Installation of observation wells and piezometers should be initiated early in the investigations so that seasonal variation in groundwater levels can be observed. Geophysical studies should be expanded to include crosshole surveys. Regional groundwater and earthquake engineering analyses should be completed. Upon completion of the GDM studies, geotechnical conditions should be developed in sufficient detail to establish design and operating requirements for a safe, functional project. If the overall project scope is such that feature design memoranda are not prepared, the geologic and soils information should be sufficient to support the preparation of plans and specifications.

(b) Feature Design Data Collection. Following the GDM study, project complexity and size will frequently require separate feature design memoranda on such structures as concrete dams, navigation locks, outlet works, road relocation and other similar project features. Generally, each of the special memoranda requires a geotechnical investigation. The investigation is an extension of previous studies, but confined to the particular area represented by the structure under study. These studies are expanded by close order subsurface investigations which may include large diameter borings, cone penetrometer tests, test excavations and grouting programs, detailed laboratory testing, pile driving and load tests, and any other method of investigations which will resolve issues or problems developed during the GDM study of the particular structure. Such issues and problems may include detailed development of underseepage, detailed evaluation of dynamic response, details of stability evaluations, and design methods to resolve these problems. For major projects requiring large amounts of concrete and/or protection stone, a separate materials feature design memorandum should be prepared. This investigation is started during the initial

GDM study period and completed early in the feature design study in order that the major structure requiring the materials can be properly designed. At the completion of the feature design memorandum studies, all geotechnical features and problems should have been identified and resolved. The final design, reflecting the geological conditions encountered at the sites, will be complete, and preparation of plans and specifications for construction of the project can proceed.

(3) Reporting for Design Investigations. The reporting of results of design investigations will be in accordance with the overall reporting requirements contained in ER 1110-2-1150. In many cases, project complexity and size will require that the design investigations be reported in the General Design Memorandum and an orderly series of feature design memoranda.

(a) General Design Memorandum. The results of all foundation and design investigations performed as part of the project engineering studies will be summarized in the General Design Memorandum and presented in detail in appendices to that report. The updated regional geology, engineering seismology, geohydrology, and earthquake engineering studies should be thoroughly documented. As previously stated, if a separate report has not been prepared, the site selection studies should be presented as an appendix to the General Design Memorandum. When feature design memoranda are not prepared, the geologic and soils information in the GDM should be sufficient to support the preparation of plans and specifications. The discussions should be augmented by geologic maps and profiles, boring, laboratory and geophysical data, and special studies relating to seismology, ground water and construction materials.

(b) Feature Design Memoranda. The geotechnical discussion that will be included in the various design feature memoranda which discuss geological aspects of the project should be similar in scope to that presented in the General Design Memorandum. However, only geotechnical data which clarify the particular intent of the feature design memorandum will be used. The discussion will be augmented by the appropriate geologic maps and profiles, boring, laboratory and geophysical data. The design memoranda that are distinctly geotechnical or have geotechnical input of significant importance, are tabulated as follows:

Site geology
Concrete materials or protection stone
Embankment and foundation
Outlet works
Spillway
Navigation lock
Instrumentation and inspection program
Initial reservoir filling and surveillance plan

2-4. Construction Activities.

a. Purpose. The construction activities are performed to prepare plans and specifications that are compatible with the project design, to insure constructibility, assure construction quality, and document actual construction conditions.

b. Scope of Geotechnical Activities. The geotechnical activities in support of the construction phase of a project can be divided into five basic phases: plans and specifications, constructibility reviews, quality assurance, foundation reports, and embankment criteria and performance report.

c. Conduct of Geotechnical Construction Activities. Guidelines for conducting construction activities are contained in the following Engineering Regulations: ER 415-1-11; ER 415-2-100; ER 1110-1-1801; ER 1110-2-1200; ER 1110-2-1901; ER 1110-2-1925; and ER 1180-1-6. Construction activities are summarized in figure 2-6 and discussed as follows:

(1) Preparation of Plans and Specifications. Plans and specifications will be prepared in accordance with ER 1110-2-1200. The plans and specifications will contain an accurate depiction of site conditions, and will be carefully prepared to eliminate conditions which might delay the work or result in claims. Plans and specifications will contain a complete graphic presentation of all borings made in the area under contract. All boring locations will be shown. Factual data representing field surveys such as geophysical and hydrological investigations shall be presented in a usable form. Because of the voluminous nature of laboratory data, that data not presented with the borings or tabulated elsewhere must be indicated as available to all prospective contractors.

(2) Constructibility Review. Constructibility review is performed in accordance to ER 415-1-11. Constructibility encompasses compatibility of design, site, materials, methods, techniques, schedules, and field conditions as well as sufficiency of details and specifications and freedom from design errors, omissions, and ambiguities. Division and District offices will coordinate project review by geotechnical, construction, and engineering personnel to improve the constructibility of design. The review process should occur during the development of the draft plans and specifications and should not be responsible for major changes in foundation and embankment design, instrumentation, or other geotechnically related features which could impact on the project schedule.

(3) Construction Management. Construction management and policies are performed in accordance with ER 415-2-100. It is the goal of

CIVIL WORKS CONSTRUCTION

CONSTRUCTIBILITY, QUALITY MANAGEMENT, AND DOCUMENTATION

PURPOSE AND SCOPE

Require the highest order of engineering and technique in the performance of work. Assure compatibility of design, site, materials, methods, techniques, schedules, and field conditions. Assure sufficiency of details and specifications and freedom from design errors, omissions, and ambiguities. Assure that construction is completed in a timely manner, and meets all requirements of the contract. Insure the preservation for future use of complete records of foundation conditions encountered during construction and of methods used to adapt structures to these conditions. Provide significant information needed to become familiar with the project, reevaluate the embankment in case of unsatisfactory performance and provide guidance for designing future projects.

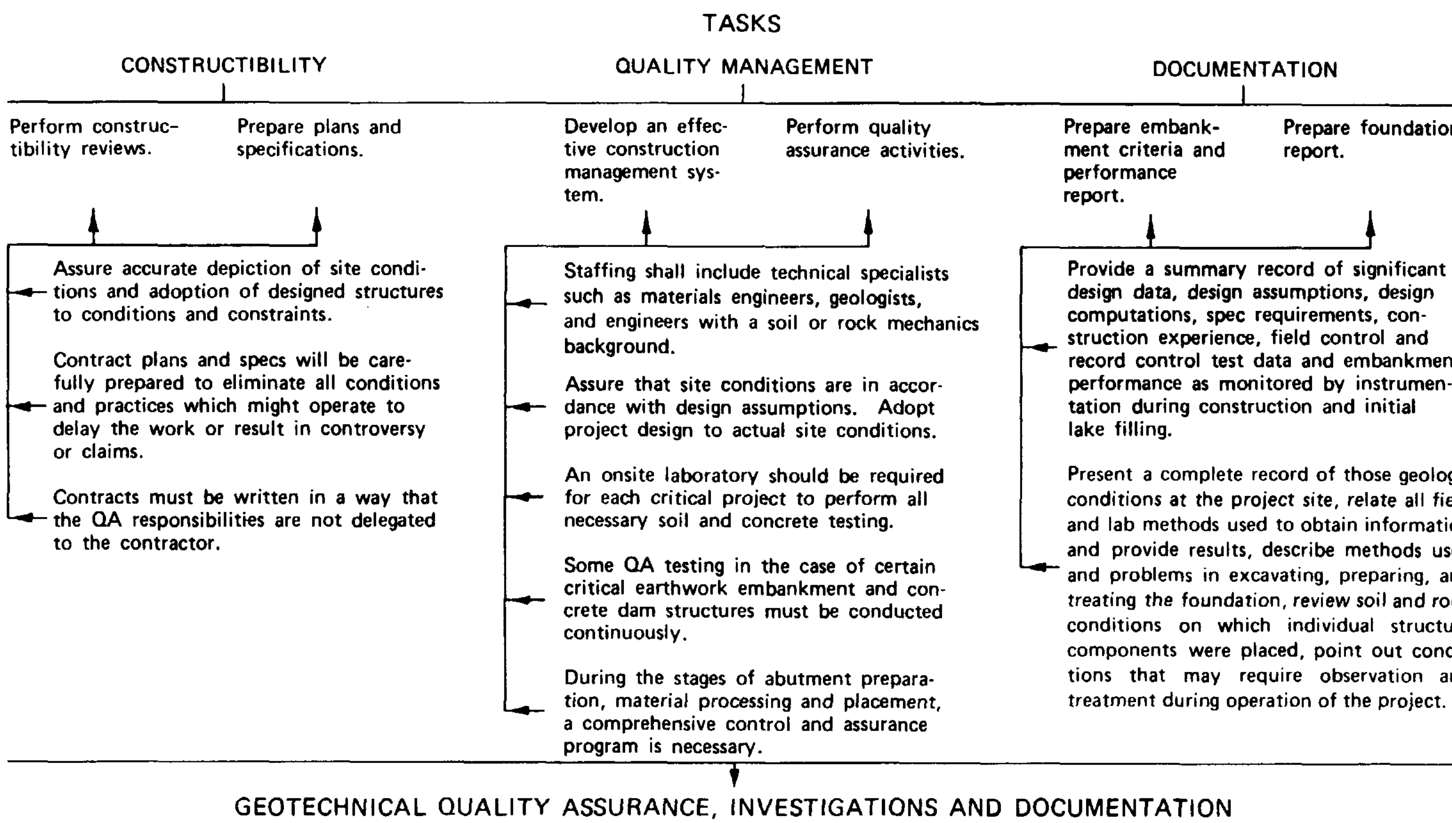

Figure 2-6. Outline of tasks for construction geotechnical activities

the Corps of Engineers to construct and deliver a quality product. The key to obtaining this objective is an effective construction management system staffed by an adequate number of trained and competent personnel. The areas of expertise shall be appropriate to the type of construction project under contract, and can include but not be limited to foundation preparation, rock and soil excavation, embankment and concrete control and emplacement, and grouting.

(4) Quality Assurance and Management. Quality assurance will be performed in accordance with ER 1180-1-6. The Government is responsible for quality assurance. The geotechnical staff assigned to the project have the responsibility to monitor, observe, and record all aspects of the construction effort relating to foundations, embankments, cuts, tunnels, and natural construction materials. Figure 2-7 shows in tabulated form some of the particular items requiring quality assurance particular to geotechnically oriented features. Quality assurance testing will be performed to assure acceptability of the completed work and verify quality control test procedures and results. An onsite laboratory should be required on major projects to perform all necessary soil and concrete testing. During construction of a project, considerable data is assembled by the project geotechnical quality assurance staff. This data consist generally of foundation mapping and treatment features, embankment-backfill performance data, grouting records, material testing data, pile driving records, and instrumentation results. Special treatment and problem areas, often requiring contract modification, should be well documented with technical data. Early in the construction of the project, the geotechnical staff should develop a data analysis and storage system which can be used to monitor the construction activities. Computer technology should be used when the size of the project warrants its use. Figure 2-8 shows in schematic form the areas where data is collected, and the use and analysis of such data.

(5) Construction Foundation and Embankment Criteria Reports. The requirements for the preparation of Foundation and Embankment Criteria Reports are contained in ER 1110-1-1801 and ER 1110-2-1901, respectively. The purpose of the foundation report is to insure the preservation for future use of complete records of foundation conditions encountered during construction and of methods used to adapt structures to these conditions. The foundation report is an important document for use in: evaluating construction claims; planning additional foundation treatment should the need arise; evaluating the cause of foundation or structural feature distress and planning remedial action to prevent failure or partial failure of a structure; and providing guidance in planning foundation explorations and in anticipating foundation problems for future comparable construction projects. The site geotechnical personnel responsible for the foundation report must begin formulation of the report as soon as possible after construction begins in order that completion of the report can be accomplished by those who participated

in the construction effort. For major embankments, an Embankment and Performance Criteria report will be prepared which will provide a summary record of significant design data, design assumptions, design computations, specification requirements, construction equipment and procedures, construction experience, field and record control test data, and embankment performance as monitored by instrumentation during construction and during initial lake fillings. The report will provide the significant information needed by engineers to familiarize themselves with the project, reevaluate the embankment in the event unsatisfactory performance occurs, and provide guidance for designing comparable future projects. The report should be authored by persons with firsthand knowledge of the project design and construction. The report should be in preparation during construction, and completed as soon as possible following reservoir filling.

Section II. Military Construction Projects

2-5. General. Program development for Military Construction Army (MCA), Air Force, and other Army projects from initial conception by the installation to final public law appropriation by Congress and construction accomplishment will require a general sequence of geotechnical investigations as shown on table 2-1. For facilities required to resist nuclear weapons effects, the guidance in this manual should be supplemented with appropriate material from TM 5-858-3.

2-6. Preconcept and Site Selection Studies.

a. Purpose and Scope. Preconcept information compilation occurs during the guidance year of the MCA program development flow. During the year, the Major Area Command (MACOMs) will prepare annual programs, set priorities, and submit these programs. The initial action consists of preparation of Project Development Brochures (PDB). The project development brochures contain the data necessary to program, budget, and initiate design of construction projects. The initial PDB is general in nature and provides information regarding project and site conditions. The initial DD Form 1391 contains the preliminary information about the project. A preliminary site survey and subsurface evaluation is included. After approval by the Department of the Army, the second PDB is formulated, generally by the District. This PDB contains total user requirements and complete site and utility support information. Information on general subsurface conditions and any special foundation requirements such as deep foundations or special treatment is included. The preconcept and site selection studies culminate in preconcept control data based on the approved PDB including a cost estimate and necessary reference data. Guidelines for development of preconcept studies are found in AR 415-15 and AR 415-20.

CIVIL WORKS CONSTRUCTION

CONSTRUCTIBILITY, QUALITY MANAGEMENT, AND DOCUMENTATION

GEOTECHNICAL ACTIVITIES

QUALITY ASSURANCE

EXCAVATION PROCEDURES

- Grades
- Unwatering
- Overburden
- Rock
  - Blast patterns/procedures
  - Fragmentation
  - Control of wall rock damage
- Slope stability
- Support
- Preliminary cleanup
- Surface protection

FOUNDATION/ABUTMENT TREATMENT

- Subsurface
  - Curtain grouting
  - Area grouting
  - Consolidation grouting
  - Caissons, trenches, slurry walls, etc.
- Surface
  - Final cleanup
  - Dental concrete
  - Shotcrete
  - Slurry grouting
- Drainage
  - Adits
  - Drain holes
  - Relief wells

EMBANKMENT/BACKFILL

- Material source
- Material placement
- Control tests
- Slope stability
- Seepage control
- Diversion and closure

Figure 2-7. Tabulation of construction quality assurance geotechnical activities

CIVIL WORKS CONSTRUCTION

CONSTRUCTIBILITY, QUALITY MANAGEMENT, AND DOCUMENTATION

GEOTECHNICAL ACTIVITIES

CONSTRUCTION INVESTIGATIONS AND DOCUMENTATION

DATA COLLECTION

REGIONAL AND SITE GEOLOGIC DATA

Review all prior maps and narratives. Add data acquired after engineering and design investigations (including preconstruction instrumentation data).

EXCAVATION AND FOUNDATION MAPPING

Prepare detailed geologic maps of all permanent excavations and structure foundations. Provide complete descriptions of all geologic and foundation treatment features.

QUALITY ASSURANCE

Compile excavation, foundation/abutment, and embankment/backfill QA activities data.

SUBSURFACE EXPLORATIONS

Drilling to confirm foundation grades, effectiveness of foundation treatment, and to investigate unanticipated conditions.

MATERIAL TESTING

Field control testing; testing to confirm design values.

INSTRUMENTATION

Installation and reading of piezometers, soil pressure devices, surface monuments, slope indicators, strong motion instruments and special instruments.

DATA ANALYSIS

PROJECT GEOLOGIC CONDITIONS

Update regional and areal geology. Revise site geologic maps and sections to show excavations, structures and general conditions.

FOUNDATION/CONSTRUCTION MATERIAL EXPLORATIONS

Assess adequacy of preconstruction explorations. Describe construction explorations.

EXCAVATION PROCEDURES

Reduce and compile data from QA activities. Discuss effectiveness of methods used and compare with design concepts.

FOUNDATION CONDITIONS

Integrate data from excavation and foundation mapping and subsurface explorations. Describe foundation surfaces, type and condition of foundation materials and encountered water, etc.

FOUNDATION AND ABUTMENT TREATMENT

Reduce and compile data from QA activities. Discuss effectiveness and compare with design concepts. Provide record of foundation approvals.

EMBANKMENT CONSTRUCTION

Summarize design. Compile data on construction procedures, control tests, placed conditions, seepage control and stability.

INSTRUMENTATION

Reduce pre- and construction data. Compare with design predictions.

Data from geotechnical quality assurance activities and construction investigations compiled and analyzed in sufficient detail for preparation of embankment criteria and performance and foundation reports. Integration of completed project into regional and local environment described. Conditions which may require observation and treatment during project operation identified. Future observations recommended.

Figure 2-8. Schematic diagram of construction geotechnical investigations and documentation

b. Scope of Geotechnical Investigations. Geotechnical investigations during preconcept studies should be performed to a level which assures adequate information to satisfy AR 415-15 and AR 415-20. They should be sufficiently complete to permit selection of the most favorable site within the regional physical setting, determine the general type of structure best suited to the site conditions, assess the geotechnical aspects of environmental impact, and ascertain the costs of the project. The scope of the investigations should not be greater than that necessary to accomplish these aims. For projects on existing military installations much of the information needed for preconcept studies will be available and the additional investigation requirements will be minimal. For projects in new areas where information is not readily available the investigation requirements will be similar to those for Civil Works Feasibility studies except emphasis will be placed on site-specific parameters relating to size and special requirements for each project.

c. Reporting. Geotechnical investigation results will be reflected in the information and decisions in the DD Form 1391 and in developed PDBs. Results of drilling and testing programs and special investigations should be compiled in summary reports.

2-7. Concept Studies.

a. Purpose and Scope. Concept studies provide drawings and data developed prior to initiation of final design, and constitute approximately 35 percent of total design. They are for the purpose of defining the functional aspects of the facility and providing a firm basis on which the district engineer can substantiate project costs and initiate final design. Included are project site plans, materials, methods of construction, and typical cross sections of structure and foundation conditions. The concept design is accomplished during the design year stage of the program development plan and leads to development of budget data. Budget data reflects firm construction requirements and contain a current working estimate. The data are used in budget hearings at the Congress.

b. Scope of Geotechnical Investigations. Geotechnical investigations for concept studies should provide similar information as included for the preconcept studies but should advance the information to the level required for design and budget development.

c. Reporting. Reporting of the results of the geotechnical investigations is included in the design analysis developed to the 35 percent design level study. Information to be presented is similar to that to be included in reporting for feasibility studies for Civil Works except additional emphasis will be placed on selection of foundation types and the influences of subsurface conditions.

2-8. Final Design Studies.

a. Purpose and Scope. Final design studies are to provide a complete set of working drawings for a project, accompanied by appropriate technical specifications, design analyses, and detailed cost estimates covering all architectural, site, and engineering details. This design is used to obtain construction bids and to serve as construction contract documents.

b. Scope of Geotechnical Investigations. Geotechnical investigations for final design should provide additional information to the preconcept and concept stage investigations for a final and complete design. All detailed considerations for economic designs, environmental influences, and construction processes should be finalized. The level of information should be similar to that for Civil Works General Design Memorandum studies.

c. Reporting. The results of the geotechnical investigations will be included in the final design analysis. Information should be similar to that reported for Civil Works General Design Memorandum studies except additional emphasis will be placed on analysis for selection of foundation types and details of the foundation design.

2-9. Construction Activities.

a. Scope of Geotechnical Investigations. In addition to quality control testing, geotechnical activities will be required during construction for special considerations or problems. Such activities will be necessary to confirm design assumptions, analyze changed conditions, determine special treatment requirements, analyze failures, and provide new materials sources.

b. Reporting. Investigation results will be provided in special summary reports and in construction foundation reports as required for major or unique projects by ER 1110-1-1801.

CHAPTER 3
REGIONAL GEOLOGIC AND SITE RECONNAISSANCE INVESTIGATIONS

3-1. General. Regional geologic and site reconnaissance investigations are made to develop the project regional geology and to scope early site investigations. The required investigation steps are shown in figure 2-1. The initial phase of geologic investigations is a thorough survey of available information. Information on topography, geology and geologic hazards, surface and ground-water hydrology, seismology, and soil and rock properties is reviewed to determine the adequacy of available data; the additional data that will be needed at specific sites; and the critical long-term studies, such as ground water and seismicity, that will be needed and will require advance planning and early action. The data also are used to develop the regional geology as an aid in defining geologic features at preliminary sites. Geologic field reconnaissances should be made at all sites that have potential and should include examination of important geologic features and potential problem areas identified during office studies. As suggested in Chapter 2, preliminary geologic models (item 16) should be developed for each site indicating possible locations and types of geologic features that would control the selection of project features. Preliminary geologic, seismic, hydrologic, and economic studies should be used to indicate the most favorable sites before preliminary subsurface investigations are started. Proper coordination and timing of these studies can minimize costs and maximize confidence in the results.

Section I. Coordination and Information Collection

3-2. Interagency Coordination and Cooperation. Sources of background information available from other organizations can have a substantial influence on project economy, safety, and feasibility. During initial investigations, project geologists may be unfamiliar with both the regional and local geology. Limited funds must be allocated to many diverse areas of study (e.g., economics, real estate, environment, hydrology, and geology). For these reasons, contacts should be made with federal, state, and local agencies to identify available sources of existing geologic information applicable to the project. A policy of formal coordination with the U. S. Geological Survey (USGS) has been established as outlined below. In addition, informal coordination should be maintained with state geological surveys since critical geologic data and technical information are often available from these agencies. Other organizations listed below may also provide valuable information.

a. Coordination with USGS. The 27 October 1978 Memorandum of Understanding (MOU) with the USGS and implementing instructions in ER 1110-1-1400 provide for exchange of information to assure that all geologic features are considered in project planning and design. The MOU outlines three main activities:

(1) The USGS provides the Corps with existing information and results of research and investigations of regional and local geology, seismology, and hydrology relevant to site selection and design.

(2) The USGS advises the Corps on geologic, seismologic, and hydrologic processes where knowledge is well developed and on specific features of site and regional problems.

(3) The Corps provides the USGS with geologic, seismologic, and hydrologic data developed from Corps studies.

The MOU requires that the USGS be notified in writing when planning studies are to be initiated at a new site or reinitiated at a dormant project. The notification should specify the location of interest and identify specific geologic, seismologic, and hydrologic considerations for which information is needed.

b. Other Organizations. Contacts and visits to offices of the following organizations can produce valuable geotechnical information in the form of published maps and reports and unpublished data from current projects.

(1) Federal Agencies.
(a) Department of Agriculture.
- Forest Service
- Soil Conservation Service
(b) Department of Energy.
- Alaska Power Administration
- Albuquerque Operations Office
- Bonneville Power Administration Office
- Idaho Operations Office
- Nevada Operations Office
- Oak Ridge Operations Office
- Richland Operations Office
- San Francisco Operations Office
(c) Department of Interior.
- Bureau of Indian Affairs
- Bureau of Land Management
- Bureau of Mines
- Bureau of Reclamation
- Fish and Wildlife Service
- Geological Survey
- National Park Service
(d) Department of Transportation, Federal Highway Administration regional and state division offices.

(e) Environmental Protection Agency regional offices.
(f) Nuclear Regulatory Commission.
(g) Tennessee Valley Authority.

(2) State Agencies.
(a) Geological Surveys and Departments of Natural Resources.
(b) Highway Departments.

(3) Municipal engineering and water services offices.

(4) State and private universities (geology and civil engineering departments).

(5) Private mining, oil, gas, sand, and gravel companies.

(6) Geotechnical engineering firms.

(7) Professional society publications.

3-3. Survey of Available Information. Information and data pertinent to the project can be obtained from a careful search through published and unpublished papers, reports, maps, records, and consultations with the USGS, state geologic and geotechnical agencies, and other federal, state, and local agencies. This information must be evaluated to determine its validity for use throughout the project's development. Deficiencies and problems must be identified early so that studies for obtaining needed information can be planned to assure economy of time and money. Table 3-1 summarizes the sources of topographic, geologic, and special maps and geologic reports.

Section II. Map Studies and Remote Sensing Methods

3-4. Map Studies. Various types of published maps, such as topographic, geologic, mineral resource, soils, and special miscellaneous maps, can be used to obtain geologic information and develop regional geology prior to field reconnaissance and exploration work. The types of available maps and their uses are described in item 44.

a. Topographic Maps. Topographic maps provide information on landforms, drainage patterns, slopes, locations of prominent springs and wet areas, quarries, man-made cuts (for field observation of geology), and mines. If older topographic maps are available, especially in mining regions, abandoned shafts, filled surface pits, and other features can be defined by comparison with later maps.

(1) Optimum use of topographic maps involves the examination of large- and small-scale maps. Certain features, such as large geologic structures, may be apparent on small-scale maps only. Conversely, the interpretation of active geomorphic processes will require accurate, large-scale maps with a small contour interval. As a general rule, the interpretation of topographic maps should proceed from small-scale (large area) maps through intermediate-scale maps to large-scale (small area) maps as the geologic investigation proceeds from the general to the specific.

Table 3-1. Sources of Geologic Information

Agency	Type of Information	Description	Remarks
USGS	Topographic maps	U. S. 7.5-minute series 1:24,000 (supersedes 1:31,680) complete for 13 states Puerto Rico 7.5-minute series 1:20,000 (supersedes 1:30,000) Virgin Island 1:24,000 series. U. S. 15-minute series 1:62,500 (1:63,360 for Alaska) U. S. 1:100,000-scale series (quadrangle, county, or regional format) U. S. 1:50,000-scale county map series U. S. 1:250,000-scale series (Alaska Reconnaissance series being replaced by more accurate Alaska 1:250,000-scale series	Orthophotoquad monocolor maps also produced in 7.5-minute and 15-minute series. New index of maps for each state started in 1976. Status of current mapping from USGS regional offices and in monthly USGS bulletin, "New Publications of the U. S. Geological Survey"
USGS	Geologic maps and reports	1:24,000 (1:20,000 Puerto Rico),1:62,500, 1:100,000, and 1:250,000 quadrangle series includes surficial bedrock and standard (surface and bedrock) maps with major landslide areas shown on later editions 1:500,000 and 1:2,500,000 (conterminous U. S., 1974)	New index of geologic maps for each state started in 1976. List of geologic maps and reports for each state published periodically
USGS	Miscellaneous maps and reports	Landslide susceptibility rating, swelling soils, engineering geology, water resources, and ground water	Miscellaneous Investigation Series and Miscellaneous Field Studies Series, maps and reports, not well cataloged; many included as open file reports
USGS	Special geologic maps	1:7,500,000 on: Karst topography and related terrain, areas of soils; areas of possible landslides; present and proposed nuclear reactor sites; surficial clay, sand, silt, and gravel deposits; areas subject to volcanic hazards; streams with flow rates expansive of 300 cu. ft/sec or greater	Prepared in preliminary form (1979) under USGS National Environmental Overview Program
USGS	Special maps	1:7,500,000 and 1:1,000,000: Limestone Resources, Solution Mining Subsidence, Quaternary Dating Applications, Lithologic Map of U. S., Quaternary Geologic Map of Chicago, Illinois, and Minneapolis, Minnesota areas	
USGS	Hydrologic maps	Hydrologic Investigations Atlases with a principal map scale of 1:24,000; includes water availability, flood areas, surface drainage precipitation and climate, geology, availability of ground and surface water, water quality and use, and streamflow characteristics	Some maps show groundwater contours and location of wells
USGS	Earthquake hazard	Seismic maps of each state (started in 1978 with Maine); field studies of fault zones; relocation of epicenters in eastern U. S.; hazards in the Mississippi Valley area; analyses of strong ground motion data; state-of-the-art workshops	Operates National Strong-Motion Network and National Earthquake Information Service publishes monthly listing of epicenters (worldwide)
USGS	Mineral resources	Bedrock and surface geologic mapping; engineering geologic investigations; map of power generating plants of U. S. (location of built, under construction, planned, and type); 7.5-minute quadrangle geologic maps and reports on surface effects of subsidence into underground mine openings of eastern Powder River Basin, Wyoming	
USGS	Bibliography	"Bibliography of North American Geology" North American, Hawaiian Islands, and Guam	Published until 1972
Geological Society of America	Bibliography	"Bibliography and Index of Geology Exclusive of North America" "Bibliography and Index of Geology"	1934-1968 1969 to present, 12 monthly issues plus yearly cumulative index ($600/year)
NOAA	Earthquake hazards	"Earthquake History of the U. S." Earthquake list and computer-printed epicenter maps	
NASA	Remote sensing data	Landsat, skylab imagery	See Table 4-2 of EP 70-1-1 for detailed information

(Continued)

Table 3-1. (Concluded)

Agency	Type of Information	Description	Remarks
USGS	Flood-prone area maps	1:24,000 series maps outlining floodplain areas not included in Corps of Engineers reports or protected by levees	Stage 2 of 1966 89th Congress House Document 465
USAEWES	Earthquake hazard	"State-of-the-Art for Assessing Earthquake Hazards in the United States," Miscellaneous Paper S-73-1	Series of 19 reports, 1973 to present
International Union of Geological Societies	Worldwide mapping	Commission for the Geological Map of the World publishes periodic reports on worldwide mapping in "Geological Newsletter"	
SCS	Soil survey reports	1:15,840 or 1:20,000 maps of soil information on photomosaic background for each county. Recent reports include engineering test data for soils mapped, depth to water and bedrock, soil profiles grain-size distribution, engineering interpretation and special features. Recent aerial photo coverage of many areas	Reports since 1957 contain engineering uses of soils mapped, parent materials, geologic origin, climate, physiographic setting, and profiles
State Geologic Agencies	Geologic maps and reports	State and county geologic maps; mineral resource maps; special maps such as for swelling soils; bulletins and monographs; well logs; water resources, groundwater studies	List of maps and reports published annually, unpublished information by direct coordination with state geologist
Defense Mapping Agency (DMA)	Topographic maps	Standard scales of 1:12,500, 1:50,000, 1:250,000 and 1:1,000,000 foreign and worldwide coverage including photomaps	Index of available maps from DMA
American Association of Petroleum Geologists	Geological highway map series	Scale approximately 1 inch equal to 30 miles shows surface geology and includes generalized time and rock unit columns, physiographic map, tectonic map, geologic history summary, and sections	Published as 12 regional maps including Alaska and Hawaii
TVA	Topographic maps, geologic maps and reports	Standard 7.5-minute TVA-USGS topographic maps, project pool maps, large-scale topographic maps of reservoirs, geologic maps and reports in connection with construction projects	Coordinate with TVA for available specific information
USBR	Geologic maps and reports	Maps and reports prepared during project planning and design studies	List of major current projects and project engineers can be obtained. Reports on completed projects by interlibrary loan or from USAE Waterways Experiment Station for many dams
USGS National Cartographic Information Center	Aerial photographic coverage	Aerial Photographic Summary Record System provides sources of planned, in progress, and existing aerial photography in eight categories	

(2) Certain engineering geology information can be inferred from topographic maps by proper interpretation of landforms and drainage patterns. Topography tends to reflect the geologic structure and composition of the underlying rocks and the geomorphic processes acting on them. The specific type of geomorphic processes and the length of time they have been acting on the particular geologic structure and rock type will control the degree to which these geologic features are evident on the topographic maps. Geologic features are not equally apparent on all topographic maps, and considerable skill and effort are required to

arrive at accurate geologic interpretations. Information of engineering significance that may be obtained or inferred from topographic maps includes physiography, general soil and rock types, bedrock structure, and geomorphic history.

b. Geologic Maps. Surficial and bedrock geologic maps can be used in developing formation descriptions, formation contacts, gross structure, fault locations, and approximate depths to bedrock (item 48). Maps of 1:250,000 scale or smaller are suitable for the development of regional geology since they can be used with remote sensing imagery of similar scale to refine regional geology and soils studies.

c. Mineral Resource Maps. Mineral resource maps produced by the USGS and state geological services are important sources of geologic information. For example, the USGS coal resources evaluation program includes preparation of geologic maps (7.5-min quadrangle areas) to delineate the quantity, quality, and extent of coal on federal lands. The USGS and state geologic service maps provide information on oil and gas lease areas and metallic mineral resource areas. Mineral resource maps also include information on natural construction materials such as quarries and sand and gravel deposits. These maps can be used in estimating the effects of proposed projects on mineral resources (such as access for future recovery, or reduction in project costs by recovery during construction).

d. Hydrologic and Hydrogeologic Maps. Maps showing hydrologic and hydrogeologic information provide a valuable source of data on surface drainage, well locations, ground-water quality, ground-water level contours, seepage patterns, and aquifer locations and characteristics.

3-5. Remote Sensing Methods. Conventional aerial photographs and various types of imagery can be used effectively for large-scale regional interpretation of geologic structure, analyses of regional lineaments, drainage patterns, rock types, soil characteristics, erosion features, and availability of construction materials. Geologic hazards, such as faults, fracture patterns, subsidence, and sink holes or slump topography, can also be recognized from air photo and imagery interpretation. Side-looking airborne radar (SLAR) provides illumination of the surface topography from low angles and from various directions, and can accentuate regional geologic structure. In addition, SLAR has the capability of penetrating cloud cover, giving it the ability to obtain images when desired, day or night and independent of seasonal changes in solar lighting. Guidance in obtaining available photographic and imagery data, interpretation, and planning for new coverage are contained in EP 70-1-1. This publication discusses special interpretation techniques and sources of commercial services.

Section III. Field Reconnaissance and Observations

3-6. Field Reconnaissance. After a complete review of available geotechnical data, a geologic field reconnaissance should be made to gather information that can be obtained without subsurface explorations or detailed study. It is desirable that the geological field reconnaissance be conducted as part of a multidisciplined effort. The composition of a team would depend upon the type and size of the project, the project effect on the area in question, and on any special problems identified as a result of early office studies. The team should include engineering geologists, soils engineers, planning engineers, and representatives of other disciplines as appropriate.

3-7. Observations. Observations made during field reconnaissances can be divided into four categories:

- Geologic/hydrologic features and geologic hazards to confirm, correct, or extend those developed during early office studies, and the preparation of regional geologic maps.
- Site accessibility, ground conditions, and right-of-entry problems that would affect field exploration work.
- Cultural features that could affect the project and exploration work.
- Condition of existing structures and construction practices that would indicate problem soil and rock conditions.

a. Observations of geologic features should include rock outcrops and soil exposures to verify or extend available geologic maps. The strike and dip of major joint sets and evidence of joint sheeting or steeply dipping beds that would affect the stability of natural or excavated slopes should also be noted. Table 3-2 outlines special geologic features and conditions which should be considered. The location of sources of construction materials, such as sand and gravel deposits, borrow areas for soils, and active or abandoned quarries, are also important. Observable hydrologic features include surface drainage flow, springs and seeps in relation to formation members, and marshy or thick vegetation areas indicating high ground-water tables.

b. Cultural features, such as the location of powerlines, pipelines, access routes, and ground conditions that could restrict the location of or access to borings, should be noted. Sources of water for early exploratory work and for project construction should be determined. Local construction practices and the condition of existing structures and roads should be observed and potential problems noted.

c. Field observations have special value in planning subsequent investigations and design studies because adverse subsurface conditions often can be anticipated from surface evidence and the regional geology. Suitable alternatives for foundation or structure types may be suggested by comprehensive field observations.

d. Field reconnaissance can emphasize the need for new mapping and new aerial photographic coverage. Such coverage should be coordinated with planners early in the study process to insure sufficient and timely coverage.

Section IV. Information Developed

3-8. Summary. Compiled and properly interpreted regional geology data, coupled with information obtained during field reconnaissances, will provide the information necessary to identify suitable sites and to determine the scope of site investigations. The completion of Regional Geology and Site Reconnaissances Studies should result in the following:

- Regional geologic conditions identified and incorporated into a regional geologic map.

  Preliminary assessment made of regional seismicity, tentative location of sources of construction materials.

- Tentative models developed of geologic conditions at suitable sites.

- Input developed for Environmental Impact Statement.

Table 3-2. Special Geologic Features and Conditions Considered in Office Studies and Field Observations

Geologic Feature or Condition	Influence on Project	Office Studies	Field Observations	Questions to Answer
Landslides	Stability of natural and excavated slopes	Presence or age in project area or at construction sites should be determined Compute shear strength at failure. Do failure strengths decrease with age of slopes--especially for clays and clay shales?	Estimate areal extent (length and width) and height of slope Estimate ground slope before and after slide (may correspond to residual angle of friction) Check highway and railway cuts and deep excavations, quarries and steep slopes	Are landslides found off site in geologic formations of same type that will be affected by project construction? What are probable previous and present groundwater levels? Do trees slope in an unnatural direction?
Faults and faulting; past seismic activity	Of decisive importance in seismic evaluations; age of most recent fault movement may determine seismic design earthquake magnitude	Determine existence of known faults and fault history from available information Examine existing boring logs for evidence of faulting from offset of strata	Verify presence at site, if possible, from surface evidence; check potential fault traces located from aerial imagery Make field check of structures, cellars, chimneys, roads, fences, pipelines, known faults, caves, inclination of trees, offset in fence lines	Are lineaments or possible fault traces apparent from regional aerial imagery?
Stress relief cracking and valley rebounding	Valley walls may have cracking parallel to valley. Valley floors may have horizontal cracking. In some clay shales stress relief from valley erosion or glacial action may not be complete	Review pertinent geologic literature and reports for the valley area. Check existing piezometer data for abnormally low levels in valley sides and foundation; compare with normal groundwater levels outside valley	Examine wells and piezometers in valleys to determine if levels are lower than normal groundwater regime (indicates valley rebound not complete)	
Sinkholes; karst topography	Major effect on location of structures and feasibility of potential site (item 13)	Examine air photos for evidence of undrained depressions	Locate depressions in the field and measure size depth and slopes. Differences in elevation between center and edges may be almost negligible or many feet. From local residents, attempt to date appearance of sinkhole	Are potentially soluble rock formations present such as limestone, dolomite, or gypsum? Are undrained depressions present that cannot be explained by glaciation? Is surface topography rough and irregular without apparent cause?
Anhydrates or gypsum layers	Anhydrates in foundations beneath major structures may hydrate and cause expansion, upward thrust and buckling Gypsum may cause settlement, subsidence, collapse or piping. Solution during life of structure may be damaging	Determine possible existence from available geologic information and delineate possible outcrop locations	Look for surface evidence of uplift; seek local information on existing structures Check area carefully for caves or other evidence of solution features	Are uplifts caused by possible hydrite expansion or "explosions"?
Caves	Extent may affect project feasibility or cost. Can provide evidence regarding faulting that may relate to seismic design. Can result from unrecorded mining activity in the area		Observe cave walls carefully for evidence of faults and of geologically recent faulting. Estimate age of any broken stalactites or stalagmites from column rings	Are any stalactites or stalagmites broken from apparent ground displacement or shaking?

(Continued)

(Sheet 1 of 3)

Table 3-2. (Continued)

Geologic Feature or Condition	Influence on Project	Office Studies	Field Observations	Questions to Answer
Erosion resistance	Determines need for total or partial channel slope protection	Locate contacts of potentially erosive strata along drainage channels	Note stability of channels and degree of erosion and stability of banks	Are channels stable or have they shifted frequently? Are banks stable or easily eroded? Is there extensive bank sliding?
Internal erosion	Affects stability of foundations and dam abutments. Gravelly sands or sands with deficiency of intermediate particle sizes may be unstable and develop piping when subject to seepage flow	Locate possible outcrop areas of sorted alluvial materials or terrace deposits	Examine seepage outcrop areas of slopes and riverbanks for piping	
Area subsidence	Area subsidence endangers long-term stability and performance of project	Locate areas of high groundwater withdrawal, oil fields and subsurface solution mining or underground mining areas	Check project area for new wells or new mining activity	Are there any plans for new or increased recovery of subsurface water or mineral resources?
Collapsing soils	Determines need for removal of shallow foundation materials that would collapse upon wetting	Determines how deposits were formed during geologic time and any collapse problems in area	Examine surface deposits for voids along eroded channels, especially in steep valleys eroded in fine-grained sedimentary formations	Were materials deposited by mud flows?
Locally lowered ground water	May cause minor to large local and area settlements and result in flooding near rivers or open water and differential settlement of structures	Determine if heavy pumping from wells has occurred in project area; contact city and state agencies and USGS	Obtain groundwater levels in wells from owners and information on withdrawal rates and any planned increases. Observe condition of structures. Contact local water plant operators	
Abnormally low pore water pressures (lower than anticipated from groundwater levels)	May indicate effective stresses are still increasing and may cause future slope instability in valley sites	Compare normal groundwater levels with piezometric levels if data is available		Is a possible cause the past reduction in vertical stresses (e.g. deep glacial valley or canal excavations such as Panama Canal in clay shales where pore water pressures were reduced by stress relief)?
In situ shear strength from natural slopes	Provides early indication of stability of excavated slopes or abutment, and natural slopes around reservoir area	Locate potential slide areas. Existing slope failures should be analyzed to determine minimum in situ shear strengths	Estimate slope angles and heights, especially at river bends where undercutting erosion occurs. Determine if flat slopes are associated with mature slide or slump topography or with erosion features	Are existing slopes consistently flat, indicating residual strengths have been developed?
Swelling soils and shales	Highly preconsolidated clays and clay shales may swell greatly in excavations or upon increase in moisture content	Determine potential problem and location of possible preconsolidated strata from available information	Examine roadways founded on geologic formations similar to those at site. Check condition of buildings and effects of rainfall and watering	Do seasonal groundwater and rainfall or watering of shrubs or trees cause heave or settlement?

(Continued)

(Sheet 2 of 3)

Table 3-2. (Concluded)

Geologic Feature or Condition	Influence on Project	Office Studies	Field Observations	Questions to Answer
Varved clays	Pervious layers may cause more rapid settlement than anticipated. May appear to be unstable because of uncontrolled seepage flow through pervious layers between overconsolidated clay layers or may have weak clay layers. May be unstable in excavations unless well points are used to control ground water	Determine areas of possible varved clay deposits associated with prehistoric lakes. Determine settlement behavior of structures in the area	Check natural slopes and cuts for varved clays; check settlement behavior of structures	
Dispersive clays	A major factor in selecting soils for embankment dams and levees	Check with Soil Conservation Service and other agencies regarding behavior of existing small dams	Look for peculiar erosional features such as vertical or horizontal cavities in slopes or unusual erosion in cut slopes. Perform "crumb" test (item 32)	
Riverbank and other Liquefaction areas	Major effect on riverbank stability and on foundation stability in seismic areas	Locate potential areas of loose fine-grained alluvial or terrace sands; most likely along riverbanks where loose sands are present and erosion is occurring	Check riverbanks for scallop-shaped failure with narrow neck (may be visible during low water). If present, determine shape, depth, average slope and slope of adjacent sections. Liquefaction in wooded areas may leave trees inclined at erratic angles. Look for evidence of sand boils in seismic areas	
Filled areas	Relatively recent filled areas would cause large settlements. Such fill areas may be overgrown and not detected from surface or even subsurface evidence	Check old topo maps if available for depressions or gullies not shown on more recent topo maps	Obtain local history of site from area residents	
Local overconsolidation from previous site usage	Local areas of a site may have been overconsolidated from past heavy loadings of lumber or material storage piles		Obtain local history from residents of area	

(Sheet 3 of 3)

CHAPTER 4
FIELD INVESTIGATIONS

4-1. General. This chapter describes in detail all elements necessary for completion of a successful field investigation program. Several elements are applicable for refinement of Regional Geology investigations discussed in Chapter 3. This chapter is subdivided into eleven sections where topics include foundation mapping, geophysical exploration, boring and exploration, groundwater and foundation seepage studies, exploratory excavations, in situ testing, test grouting, and test quarries and test fills. The order of the sections generally reflects a districts approach to a field investigation, that is, generalized investigations leading to more complex and sophisticated field testing as project development advances. The guidance provided in this chapter also applies to field activities during construction including excavation and foundation mapping procedures.

4-2. Protection of the Environment. After the locations for field investigations work have been determined, routes of access to the area and the specific sites for borings and excavations should be selected with care in order to minimize damage to the environment. Operation of equipment will 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. After the exploratory sites have served their purpose, the disturbed areas will be restored to a natural appearance.

Section I. Geologic Field Mapping

4-3. Areal Mapping. The purpose of areal mapping is to develop an accurate picture of the geologic framework of the project area. The area and the degree of detail to be mapped can vary widely depending o the type and size of project and on the regional geology. In general, the area to be mapped should include the project site(s) as well as the surrounding area that could influence or could be influenced by the project. The information available from other sources should have been identified and collected during the preliminary investigations (Chapter 3). If this was not done, or if for any reason it appears that additional useful information may be available, this information should be obtained and evaluated before expensive field investigations are started. Only when existing geologic studies of an area have been combined with current geologic mapping and appropriate remote sensing techniques can an areal mapping program be considered complete.

a. Reservoir Projects. Geologic features within the reservoir and adjacent areas that should be studied and mapped include the following:

- Faults, joints, stratigraphy, and other significant geologic features.
- Karst topography or other signs of high reservoir leakage potential.
- Water well levels, springs, surface water, water-sensitive vegetation, or other evidence of the ground-water regime.
- Soluble or swelling rocks such as gypsum or anhydrite.
- Potential landslide areas around the reservoir rim.
- Valuable mineral resources.
- Mine shafts, tunnels, and gas and oil wells.
- Potential borrow and quarry areas and sources of construction materials.
- Shoreline erosion potential.

b. Other Projects. The geologic features listed above are applicable in part to navigation locks and dams, mainline levees, coastal and harbor protection projects, or large or complex military projects. However, the scope and detail of the area mapped depends on the type and size of the project.

4-4. Site Mapping. Large-scale and detailed geologic maps should be prepared for specific sites of interest within the project area and should include proposed structure areas and borrow and quarry sites. Development of the geologic features of overburden and bedrock materials is essential in site mapping and subsequent explorations. The determination of the subsurface features should be derived from a coordinated, cooperative study by geotechnical engineers and geologists. The geologist should contribute information on origin, distribution, and manner of deposition of the overburden and bedrock, and the geotechnical engineer should determine the engineering properties of these materials, the manner of application to design, and the adaptation of proposed structures to foundation conditions.

a. Structure Sites. A good preliminary geologic map should be prepared prior to making any subsurface borings to provide an approximate picture of the geologic conditions and hazards at a site. Such a map will permit borings to be strategically located and can be particularly important when funds for foundation investigations are limited. For each proposed boring, an estimate should be made of the subsurface conditions that will be encountered, such as depths to critical contacts. This estimate is nearly always possible if geologic mapping has been performed to determine the geologic structure, lithology, and stratigraphy, at least in an approximate manner. The process of progressively refining the model of the geologic structure and stratigraphy by comparison with boring information is the most efficient and cost-effective means to develop a complete understanding of the geologic site conditions.

b. Borrow and Quarry Sites. Sources of materials for embankment construction, riprap protection, and aggregates for concrete or road construction can often be located and evaluated during the course of regional mapping. It is sometimes necessary to expand the field area in order to locate suitable quantities of construction materials. In these instances, various remote sensing techniques including aerial photography may be useful. Other plans should be considered that could use materials closer to the project but lower in quality. A complete borrow and quarry source map will include all soil types encountered and their field classification, and all rock types with adequate descriptions of surficial weathering, hardness, and joint spacings. By making field estimates of the depths of various deposits, a geologic map may be used to estimate quantities available. Geologic maps can also be used to make a preliminary layout of haul and access roads and to estimate haul distances.

4-5. Construction Mapping. Foundation mapping is required by ER 1110-1-1801, Construction Foundation Reports (see Chap. II, para. 2-5c(5)) as a method which can show geologic conditions as encountered during construction in concise detail. Traditionally, they are geologic maps with details on structural, lithologic, and water-oriented features. They can represent structure foundations, cut slopes, and geologic features in tunnels or large chambers. These maps should be prepared for soil and bedrock areas, and show any feature installed to improve, modify, or control geologic conditions. Some examples are rock reinforcing systems, permanent dewatering systems, and special treatment areas. The mapping will be performed by a geologist or geological engineer regardless of the size of the project. The mapping of foundations is usually performed after the foundation has been cleaned just prior to the placement of concrete or backfill. The surface cleanup at this time is generally sufficient to permit the observation and recording of all geologic details in the foundation. Appendix B provides detailed guidance on technical procedures for mapping of foundations. Mapping of tunnels and other underground openings must be planned differently than foundation mapping. Design requirements for support of the openings may require installation of support before an adequate cleanup can be made for mapping purposes. Consequently, mapping should be performed as the heading or opening is advanced, and during the installation of support features. This requires a well trained geologist or geological engineer at the excavation at all times. Technical procedures for mapping tunnels are found in Appendix C and can be modified for large chambers. Other geologic maps of the project, which could relate to postconstruction hazards or problems, also should be prepared for the project foundation report.

Section II. Geophysical Explorations

4-6. General. Geophysical exploration consists of making indirect measurements from the earth's surface or in boreholes to obtain subsurface information. Geologic information is obtained through analysis or interpretation of these measurements. Boreholes or other subsurface explorations are needed for reference and control when geophysical methods are used. Geophysical explorations are of greatest value when performed early in the field exploration program in combination with limited subsurface explorations. They are appropriate for a rapid location and correlation of geologic features such as stratigraphy, lithology, discontinuities, ground water, and the in situ measurement of elastic moduli and densities. The cost of geophysical explorations is generally low compared with the cost of core borings or test pits, and considerable savings may be realized by judicious use of these methods.

4-7. Methods. The five major geophysical exploration methods are seismic, electrical resistivity, sonic, magnetic, and gravity. Of these, the seismic and electrical resistivity methods have found the most practical application to the engineering problems of the Corps of Engineers. The applications, advantages, and limitations of selected geophysical methods are summarized in table 4-1 and rated in table 4-2. EM 1110-1-1802 provides detailed guidance on the use and interpretation of surface and subsurface methods. More recently, special applications of microgravimetric techniques for sites with faults, fracture zones, cavities, and other bedrock irregularities have been made (item 9).

Section III. Borings

4-8. General. Borings are required to characterize the basic geologic materials at a project. Borings are classified broadly as disturbed, undisturbed, and core. Occasionally, borings are made for purposes not requiring the recovery of samples. The major uses for which borings are made are as follows.

- Define geologic stratigraphy and structure.
- Obtain samples for index testing.
- Obtain ground-water data.
- Perform in situ tests.
- Obtain samples to determine engineering properties.
- Install instrumentation.
- Establish foundation elevations for structures.
- Determine the engineering characteristics of existing structures.

Table 4-1. Application of Selected Geophysical Methods to Determination of Engineering Parameters[a]

Geophysical Method	Basic Measurement	Application	Advantages	Limitations
		Surface		
Refraction (seismic)	Travel time of compressional waves through subsurface layers	Velocity determination of compression wave through subsurface. Depths to contrasting interfaces and geologic correlation of horizontal layers	Rapid, accurate, and relatively economical technique. Interpretation theory generally straightfoward and equipment readily available	Incapable of detecting material of lower velocity underlying higher velocity. Thin stratum sometimes not detectable. Interpretation is not unique
Reflection (seismic)	Travel time of compressional waves reflected from subsurface layers	Mapping of selected reflector horizons. Depth determinations, fault detection, discontinuities, and other anomalous features	Rapid, thorough coverage of given site area. Data displays highly effective	Without controlled high-frequency seismic sources, resolution is very limited for shallow applications (current research efforts directed toward controlled sources and data processing show promise for engineering applications)
Rayleigh wave dispersion	Travel time and period of surface Rayleigh waves	Inference of shear wave velocity in near-surface materials	Rapid technique which uses conventional refraction seismographs	Requires long line (large site). Requires high-intensity seismic source rich in low-frequency energy. Interpretation complex

(Continued)

a From EM 1110-1-1802.

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Table 4-1. (Continued)

Geophysical Method	Basic Measurement	Application	Advantages	Limitations
Vibratory (seismic)	Travel time or wavelength of surface Rayleigh waves	Inference of shear wave velocity in near-surface materials	Controlled vibratory source allows selection of frequency, hence wavelength and depth of penetration (up to 200 ft). Detects low-velocity zones underlying strata of higher velocity. Accepted method	Requires large vibratory source, specialized instrumentation, and interpretation
Reflection profiling (seismic-acoustic)	Travel times of compressional waves through water and subsurface materials and amplitude of reflected signal	Mapping of various lithologic horizons; detection of faults, buried stream channels, and salt domes, location of buried man-made objects; and depth determination of bedrock or other reflecting horizons	Surveys of large areas at minimal time and cost; continuity of recorded data allows direct correlation of lithologic and geologic changes; correlative drilling and coring can be kept to a minimum	Data resolution and penetration capability is frequency dependent; sediment layer thickness and/or depth to reflection horizons must be considered approximate unless true velocities are known; some bottom conditions (e.g., organic sediments) prevent penetration; water depth should be at least 15 to 20 ft for proper system operation

(Continued)

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Table 4-1. (Continued)

Geophysical Method	Basic Measurement	Application	Advantages	Limitations
Electrical resistivity	Electrical resistance of a volume of material between probes	Complementary to refraction (seismic). Quarry rock, ground water, sand and gravel prospecting. River bottom studies and cavity detection	Economical nondestructive technique. Can detect large bodies of "soft" materials	Lateral changes in calculated resistance often interpreted incorrectly as depth related; hence, for this and other reasons, depth determinations can be grossly in error. Should be used in conjunction with other methods, i.e., seismic
Acoustic (resonance)	Amplitude of acoustically coupled sound waves originating in an air-filled cavity	Traces (on ground surface) lateral extent of cavities	Rapid and reliable method. Interpretation relatively straightforward. Equipment readily available	Must have access to some cavity openings. Still in experimental stage - limits not fully established
Radar	Travel time and amplitude of a reflected signal microwave	Rapidly profiles layering conditions. Stratification, dip, water table, and presence of many types of anomalies can be determined	Very rapid method for shallow site investigations. On line digital data processing can yield "on site" look. Variable density display highly effective	Transmitted signal rapidly attenuated by water. Severely limits depth of penetration. Multiple reflections can complicate data interpretation. Equipment costly. Requires highly specialized personnel. Still in early stages of development

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Table 4-1. (Continued)

Geophysical Method	Basic Measurement	Application	Advantages	Limitations
Gravity	Variations in gravitational field	Detects anticlinal structures, buried ridges, salt domes, faults, and cavities	Provided extreme care is exercised in establishing gravitational references, reasonably accurate results can be obtained	Equipment very costly. Requires specialized personnel. Anything having mass can influence data (buildings, automobiles, etc). Data reduction and interpretation are complex. Topography and strata density influence data
Magnetic	Variations of earth's magnetic field	Determines presence and location of magnetic materials in the subsurface. Locates ore bodies	Minute quantities of magnetic materials are detectable	Only useful for locating magnetic materials. Interpretation highly specialized. Calibration on site extremely critical. Presence of any metallic objects influences data
		Borehole		
Uphole/downhole (seismic)	Vertical travel time of compressional and/or shear waves	Velocity determination of vertical P- and/or S-waves. Identification of low-velocity zones	Rapid technique useful to define low-velocity strata. Interpretation straightforward	Care must be exercised to prevent undesirable influence of grouting or casing

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Table 4-1. (Continued)

Geophysical Method	Basic Measurement	Application	Advantages	Limitations
Wavefront (seismic) Meissner	Diagonal (both horizontal and vertical) travel time of compressional waves	Means of detecting large subsurface anomalies, such as cavities. Ray travel paths and arrival times used to generate effectively contoured presentation	With discretion, large anomalies can be detected. Gives thorough site coverage. Uphole/downhole data available from survey	Costly method to conduct and interpret. Assumes horizontal layering (not always valid). Highly specialized personnel required for data interpretation. Still being researched for validation
Crosshole (seismic)	Horizontal travel time of compressional and/or shear waves	Velocity determination of horizontal P- and/or S-waves. Elastic characteristics of subsurface strata can be calculated	Generally accepted as producing reliable results. Detects low-velocity zones provided borehole spacing not excessive	Careful planning with regard to borehole spacing based upon geologic and other seismic data an absolute necessity. Shell's law of refraction must be applied to establish zoning. A borehole deviation survey must be run. Requires highly experienced personnel. Repeatable source required.

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Table 4-1. (Continued)

Geophysical Method	Basic Measurement	Application	Advantages	Limitations
Borehole spontaneous potential	Natural earth potential	Correlates deposits, locates water resources, studies rock deformation, assesses permeability, and determines ground-water salinity	Widely used, economical tool. Particularly useful in the identification of highly porous strata (sands, etc.)	Log must be run in a fluid filled, uncased boring. Not all influences on potentials are known
Single-point resistivity	Strata electrical resistance adjacent to a single electrode	In conjunction with spontaneous potential, correlates strata and locates porous materials	Widely used, economical tool. Log obtained simultaneous with spontaneous potential	Strata resistivity difficult to obtain. Log must be run in a fluid filled, uncased boring. Influenced by drill fluid
Long and short normal resistivity	Near-hole electrical resistance	Measures resistivity within a radius of 16 and 64 in.	Widely used, economical tool	Influenced by drill fluid invasion. Log must be run in a fluid filled, uncased boring
Lateral resistivity	Far-hole electrical resistance	Measures resistivity within a radius of 18.7 ft	Less drill fluid invasion influence	Log must be run in a fluid filled, uncased boring. Investigation radius limited in low moisture strata
Induction resistivity	Far-hole electrical resistance	Measures resistivity in air- or oil-filled holes	Log can be run in a nonconductive casing	Large, heavy tool

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Table 4-1. (Continued)

Geophysical Method	Basic Measurement	Application	Advantages	Limitations
Borehole imagery (acoustic)	Sonic image of borehole wall	Detects cavities, joints, fractures in borehole wall. Determine attitude (strike and dip) of structures	Useful in examining casing interior. Graphic display of images. Fluid clarity immaterial	Highly experienced operator required. Slow log to obtain. Probe awkward and delicate. Borehole must be less than 6 in. diameter
Continuous sonic (3-D) velocity	Time of arrival of P- and S-waves in high-velocity materials	Determines velocity of P- and S-waves in near vicinity of borehole. Potentially useful for cavity and fracture detection. Modulus determinations. Sometimes S-wave velocities are inferred from P-wave velocity and concurrently run nuclear logs through empirical correlations	Widely used method. Rapid and relatively economical. Variable density display generally impressive. Discontinuities in strata detectable	Shear wave velocity definition questionable in unconsolidated materials and soft sedimentary rocks. Only P-wave velocities greater than 5000 fps can be determined
Natural gamma radiation	Natural radioactivity	Lithology, correlation of strata, may be used to infer permeability. Locates clay strata and radioactive minerals	Widely used, technically simple to operate and interpret	Borehole effects, slow logging speed, cannot directly identify fluid, rock type, or porosity. Assumes clay minerals contain potassium 40 isotope

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Table 4-1. (Continued)

Geophysical Method	Basic Measurement	Application	Advantages	Limitations
Gamma spectrography	Concentration of selected radioactive elements	Natural gamma plus energetic gamma ray spectrum, shale content		Complex electronics required. Cannot directly identify fluid, rock type, or porosity. Not widely used. Still experimental
Gamma-gamma density	Electron density	Determines rock density of subsurface strata	Widely used. Can be applied to quantitative analyses of engineering properties. Can provide porosity	Borehole effects, calibration, source intensity, chemical variation in strata affect measurement precision. Radioactive source hazard
Neutron porosity	Hydrogen content	Moisture content (above water table) total porosity (below water table)	Continuous measurement of porosity. Useful in hydrology and engineering property determinations. Widely used	Borehole effects, calibration, source intensity, bound water, all affect measurement precision. Radioactive source hazard
Neutron activation	Neutron capture	Concentration of selected radioactive materials in strata	Detects elements such as U, Na, Mn. Used to determine oil-water contact (oil industry) and in prospecting for minerals (AL, Cu)	Source intensity, presence of two or more elements having similar radiation energy affect data
Borehole magnetic	Nuclear precession	Deposition, sequence, and age of strata	Distinguishes ages of lithologically identical strata	Earth field reversal intervals under study. Still subject of research

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Table 4-1. (Continued)

Geophysical Method	Basic Measurement	Application	Advantages	Limitations
Borehole gravity	Gravity intensity	Strata densities	Large material mass averaged for less borehole influence on density measurements	Costly equipment and slow process. Still subject of research
Mechanical caliper	Diameter of borehole	Measures borehole diameter	Useful in a wet or dry hole	Must be recalibrated for each run. Averages 3 diameters
Acoustic caliper	Sonic ranging	Measures borehole diameter	Large range. Useful with highly irregular shapes	Requires fluid filled hole and accurate positioning
Temperature	Temperature	Measures temperature of fluids and borehole sidewalls. Detects zones of inflow or fluid loss	Rapid, economical, and generally accurate	None of importance
Fluid resistivity	Fluid electrical resistance	Water-quality determinations and auxiliary log for rock resistivity	Economical tool	Borehole fluid must be same as ground water
Tracers	Direction of fluid flow	Determines direction of fluid flow	Economical	Environmental considerations often preclude use of radioactive tracers
Flowmeter	Fluid velocity and quantity	Determines velocity of subsurface fluid flow and, in most cases, quantity of flow	--	--

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Table 4-1. (Concluded)

Geophysical Method	Basic Measurement	Application	Advantages	Limitations
Sidewall sampling	--	--	--	--
Fluid sampling	--	--	--	--
Borehole dipmeter	--	--	--	--
Borehole surveying	Azimuth and declination of borehole drift	Determines the amount and direction of borehole deviation from the vertical normal	A reasonably reliable technique. Method must be used during the conduct of crosshole surveys to determine distance between seismic source and receivers	Errors are cumulative, so care must be taken at each measurement point to achieve precise data

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Table 4-2. Numerical Rating of Geophysical Methods to Provide Specific Engineering Parameters[a]

Engineering Application

Geophysical Method	Depth to Rock	P-Wave Velocity	S-Wave Velocity	Shear Modulus	Young's Modulus	Poisson's Ratio	Lithology	Material Boundaries Stratigraphy	Dip of Strata	Density	In Situ State of Stress	Temperature	Permeability	Percent Saturation	Ground-Water Table	Ground-Water Quality	Ground-Water Aquifers	Flow Rate and/or Direction	Borehole Diameter	Obstructions	Rippability	Fault Detection	Cavity Detection	Cavity Delineation	Location of Ore Bodies	Borehole Azimuth and Inclination
Surface																										
Refraction (seismic)	4	4	4	4	4	4	1	3	4	2	1	0	0	2	2	0	2	0	0	2	4	3	2	2	3	0
Reflection (seismic)	4	0	0	0	0	0	1	4	4	0	0	0	0	0	2	0	1	0	0	2	0	4	3	3	3	0
Rayleigh wave dispersion	1	0	2	2	0	0	1	3	0	2	1	0	0	0	0	0	0	0	0	1	0	0	0	1	2	0
Vibratory (seismic)	2	0	4	4	4	0	1	3	0	2	1	0	0	0	0	0	0	0	0	2	2	1	2	2	3	0
Reflection profiling (seismic-acoustic)	4	0	0	0	0	0	1	4	4	0	0	0	0	0	0	0	0	0	0	3	0	4	3	3	4	0
Electrical potential[b]	0	0	0	0	0	0	0	1	0	0	0	0	1	1	2	3	3	3	0	0	0	3	3	3	4	0
Electrical resistivity	3	0	0	0	0	0	1	3	2	0	0	0	2	1	4	0	4	2	0	3	2	0	4	4	4	0
Acoustic (resonance)[b]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	4	0	0
Radar[b,c]	3	0	0	0	0	0	1	3	2	0	0	0	2	3	3	0	0	2	0	3	0	3	3	3	3	0
Electromagnetic[b]	4	0	0	0	0	0	3	4	1	0	0	0	1	2	3	1	2	0	0	0	0	3	0	0	4	0
Gravity	3	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	4	0	1	3	3	3	0
Magnetic[b,c]	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	4	0
Borehole																										
Uphole/downhole (seismic)	4	4	4	4	4	4	1	4	0	2	1	0	0	2	2	0	2	0	0	1	2	3	0	2	2	0
Wavefront (seismic) Meissner	4	4	0	0	0	4	1	4	3	2	1	0	0	2	2	0	2	0	0	4	4	3	3	3	3	0
Crosshole (seismic)	4	4	4	4	4	4	1	4	2	2	1	0	0	2	2	0	2	0	0	3	2	3	3	2	3	0
Crosshole acoustic[b]	4	4	4	4	4	0	1	3	4	0	0	0	1	0	3	0	0	0	0		3	3	3	3	0	0
Crosshole resistivity[b]	3	0	0	0	0	0	1	3	1	0	0	0	1	0	3	0	3	0	0		0	2	3	3	0	0
Borehole spontaneous potential	2	0	0	0	0	0	4	4	4	2	0	0	0	0	4	2	4	0	0	1	0	2	2	1	3	0
Single-point resistivity	2	0	0	0	0	0	4	4	1	0	0	0	0	1	4	2	4	0	0	1	0	1	1	1	2	0
Long and short normal resistivity	2	0	0	0	0	0	4	4	1	1	0	0	0	4	3	0	2	0	0	0	0	1	1	2	4	0
Lateral resistivity	2	0	0	0	0	0	3	4	1	1	0	0	0	4	3	0	2	0	0	0	0	1	1	2	4	0
Induction-resistivity[b]	2	0	0	0	0	0	4	4	1	1	0	0	0	4	3	0	2	0	0	0	0	1	1	2	4	0
Borehole imagery acoustic	4	0	0	0	0	0	2	3	1	0	1	0	2	0	2	0	0	0	0	1	0	2	2	3	0	0
Interval (3D) velocity	2	4	2	2	2	2	2	3	1	2	1	0	0	1	1	0	0	0	0	1	0	3	2	2	2	0
Natural gamma radiation	2	0	0	0	0	0	4	4	1	2	0	0	3A	1A	3A	2	2A	1	0	0	0	3A	1	1	4	0
Gamma spectrography[b]	2A	0	0	0	0	0	4	3A	1	0	0	0	2A	1A	2A	0	0	0	0	0	0	0	0	0	3A	0
Gamma-gamma density	3A	0	0	0	0	0	4	4	1	3A	0	0	2A	3A	2A	0	0	0	0	0	3	3A	2	1	4	0
Neutron porosity	2A	0	0	0	0	0	4	4	1	3A	0	0	2	3A	3A	0	0	0	0	0	0	3A	2	1	4	0
Neutron activation[b]	2A	0	0	0	0	0	3	1	1	0	0	0	2A	2	3A	0	0	2	0	1	0	1	0	0	4	0
Borehole magnetic[b]	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0
Borehole gravity[b]	1	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	2	4	0	0
Mechanical caliper	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0
Acoustic caliper	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	2	1	0	0	0	0	0	0
Temperature	0	0	0	0	0	0	0	0	0	0	1	4	1	0	2	4	4	2	0	0	0	0	1	2	1	0
Fluid resistivity	0	0	0	0	0	0	0	1	0	1	0	0	1	4	4	4	4	0	0	0	0	0	3	1	1	0
Tracers[b]	0	0	0	0	0	0	1	0	0	0	0	0	1	0	2	0	4	4	0	1	0	0	0	3	0	0
Flowmeter[b]	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2	0	4	4	0	2	0	0	0	2	0	0
Sidewall sampling[b]	4	0	0	0	0	0	4	4	1	4	2	0	4	4	2	0	0	0	0	2	2	2	1	0	4	0
Fluid sampling[b]	0	0	0	0	0	0	0	0	0	0	0	4	1	0	4	4	4	2	0	0	0	0	0	0	0	0
Borehole dipmeter[b]	0	0	0	0	0	0	2	1	4	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	1	2
Borehole surveying	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4

[a] Numerical rating refers to applicability of method in terms of current use and future potential:

0 - Not considered applicable
1 - Limited
2 - Used or could be used, but not best approach
3 - Excellent potential but not fully developed
4 - Generally considered as excellent approach; state of art well developed
A - In conjunction with other electrical and nuclear logs

[b] Methods not included in EM 1110-1-1802.

[c] Airborne or inhole survey capability not considered.

Borings are frequently used for more than one purpose, and it is not uncommon to use a boring for purposes not contemplated when it was made. This one reason makes it important to have a complete log of every boring, even if there may not be an immediate use for some of the information. Initial exploration phases should concentrate on providing overall information about the site. Probing or fishtailing drilling methods may be used where specific geologic data is required, such as "top of rock" and soil or rock samples are not required.

4-9. Boring Methods. Many methods are used to make borings. Some of the more common methods are discussed in the following paragraphs. Many of these are also discussed in detail in EM 1110-2-1907. Some of the factors that affect the choice of methods are listed below.

- Purpose and information required.
- Equipment availability.
- Experience and training of available personnel.
- Type of materials anticipated.
- Terrain and accessibility.
- Cost.
- Environmental impacts.

a. Auger Borings. Auger borings provide disturbed samples that are suitable for determining soil type, Atterberg limits, and other index properties but give limited information on subsoil stratification, consistency, or sensitivity. Auger borings are most useful for preliminary soil investigations of soil type, advancing holes for other sampling methods, and determining the top of rock. They should not be used for foundation investigations, slope stability studies, or other uses where stratification and sample consistency are important. Auger borings can be made using posthole, helical, barrel, or bucket augers. Auger samples are difficult to obtain below the ground-water table, except in clays.

b. Drive Borings. Drive borings provide disturbed samples that contain all soil constituents, retain natural stratification, and can supply data on penetration resistance. Drive samplers normally range from 2 to 5 in. in diameter. Drive borings are suitable for exploring foundations and, in larger sizes, are useful for borrow explorations. The sampler can be of the splitspoon or solid tube type. The Standard Penetration Test (SPT) is performed with a 2-in.-diameter splitspoon sampler. The degree of disturbance in the sample is determined by the method used to obtain the sample, and can be minimized by a careful selection of the sampling device.

c. Cone Pentration Borings. The Cone Penetration Test (CPT) or Dutch cone boring is an in situ testing method for evaluating detailed soil stratigraphy as well as estimating geotechnical engineering properties. The CPT involves hydraulically pushing a 1.4-in.-diam special probe into the earth while performing two measurements, cone resistance and sleeve friction resistance. The probe is normally pushed from a special heavy duty truck but can also be performed from a trailer or drill rig.

d. Undisturbed Borings. True "undisturbed" samples cannot be obtained because of the adverse effects resulting from sampling, shipping, or handling. However, modern undisturbed samplers used with great care can obtain samples that are satisfactory for shear strength, consolidation, permeability, and density tests, provided the possible effects of sample disturbance are considered. Undisturbed samples can be sliced to permit detailed study of subsoil stratification, joints, fissures, failure planes, and other details. Undisturbed samples of clays and silts can be obtained as well as nearly undisturbed samples of some sands. There are no standard or generally accepted methods for undisturbed sampling of noncohesive soils. One method that has been used is to obtain 3-in. Shelby tube samples, drain them, and then freeze them prior to transporting them to the laboratory. Another method recently used consists of in situ freezing, followed by sampling with a rotary core barrel. Care is necessary in transporting any undisturbed sample, and special precautions must be taken when transporting sands and silts.

e. Rock Core Borings. In most cases, the standard NW or NQ core provides a satisfactory sample for preliminary exploration work and, in many instances, for more advanced design studies. Table 4-3 summarizes core sizes commonly used in engineering studies. The NW-size sample can be used for determining unconfined compressive strength in the laboratory and petrographic analysis samples. Core recovery in zones of weak or intensely fractured rock is particularly important since these zones are usually the critical areas from the standpoint of foundation loading and stability. The use of larger diameter core barrels in soft, weak, or fractured strata can improve core recovery and does provide a statistically better size sample for laboratory testing. While the majority of rock core borings are drilled vertically, inclined borings and in some cases oriented cores are required to adequately define stratification and jointing. Inclined borings should be used to investigate steeply inclined jointing in abutments and valley sections for dams, along spillway and tunnel alinements, and in foundations for other structures. In nearly vertical bedding, inclined borings can be used to reduce the total number of borings needed to obtain core samples of all strata. Where precise geological structure is required from core samples, techniques involving oriented cores are sometimes employed. In these procedures, the core is scribed or engraved with a special drilling

Table 4-3. Typical Diamond Core Drill
Bit and Reaming Shell Dimensions

Size	O.D. (in.)	I.D. (in.)	Reaming Shell O.D. (in.)
	"W" Group - "G" & "M" Design		
EWG, EWM	1.470	0.845	1.485
AWG, AWM	1.875	1.185	1.890
BWG, BWM	2.345	1.655	2.360
NWG, NWM	2.965	2.155	2.980
HWG	3.890	3.000	3.907
	"W" Group - "T" Design		
RWT	1.160	0.735	1.175
EWT	1.470	0.905	1.485
AWT	1.875	1.281	1.890
BWT	2.345	1.750	2.360
NWT	2.965	2.313	2.980
HWT	3.890	3.187	3.907
	Large-Diameter Design		
2-3/4 X 3-7/8	3.840	2.690	3.875
4 X 5-1/2	5.435	3.970	5.495
6 X 7-3/4	7.655	5.970	7.750

NOTES:

1. All the above dimensions are taken from the Diamond Core Drill Manufacturers Association (DCDMA) Standards, Bulletin No. 4, 1980.

2. The three-letter nomenclature is defined below.

a. The first letter designates the approximate hole size.

b. The second letter designates a particular group of tools (letters X and W are synonymous).

c. The third letter designates a particular design of a tool.

3. The "G" design replaces the "X" design. The "X" design is now obsolete.

4. The above tabulation does not include any dimensions for wireline systems. All dimensions of a wireline system must be related to a particular manufacturer's design, a majority of which are compatible in diameter size with the DCDMA's hole size and nomenclature. Wireline system dimensions are generally available from the manufacturer.

tool (item 17) so that its orientation is preserved. In this manner, both the dip and strike of any joint, bedding plane, or other planar surface can be ascertained. A more common procedure for obtaining dip and strike of structural features is the use of borehole photography or television.

f. Large-Diameter Borings. Large-diameter borings, 2 ft or more in diameter, are not frequently used. However, their use permits direct examination of the sidewalls of the boring or shaft and provides access for obtaining high-quality undisturbed samples. These advantages are often the principal justification for large-diameter borings. Direct inspection of the sidewalls may reveal details, such as thin weak layers or old shear planes, that may not be detected by continuous undisturbed sampling. Augers are normally used in soils and soft rock, and large-diameter core barrels are used in hard rock.

Section IV. Drilling and Inspection

4-10. General. A major part of field investigations is the development of accurate borehole logs on which subsequent geologic and geotechnical information will be based. A field drilling log for each borehole can provide an accurate and comprehensive record of the stratigraphy and lithology of soils and rocks encountered in the borehole together with any other relevant information obtained during drilling, sampling, and in situ testing. To accomplish this objective, a field inspector will be present during drilling and should be an experienced engineering geologist or geotechnical engineer. The duties of the field inspector include the following:

- Observing, classifying, and describing geologic materials.
- Selecting and preserving samples.
- Logging and disposition of core samples.
- Completing the drilling log, ENG FORM 1836.
- Recording information and data from in situ tests.

The logs of borings are normally made available to contractors for use in preparing their bids. The descriptions contained on the logs of borings give the contractor an indication of the type of soils to be encountered and their in situ condition. Guidance on soil identification and description, coring, and core logging is provided in the remainder of this section.

4-11. Soil Identification and Description. A thorough and accurate description of soils is important in establishing general engineering properties for design and anticipated behavior during construction. The description must identify the type of soil (clay, sand, etc.) and place it within established groupings, and include a general description of the condition of the material (soft, firm, loose, dense, dry, moist, etc.). Classification of the soils within a site provides guidance for further subsurface exploration, selection of samples for detailed testing, and development of generalized subsurface profiles. Soil classification and other boring data are recorded on the logs of borings. Soils should be described in accordance with ASTM D 2488, "Description of Soils (Visual-Manual Procedure)." Some of the procedures, such as determining dry strength, may be impractical under certain field conditions, and may be omitted where necessary. However, the checklists included in the procedure, if followed conscientiously, provide for a thorough description of soils. Examples for presenting soils data on ENG FORM 1836 are shown in Appendix D.

4-12. Coring. Core drilling, when carefully executed and properly reported, can produce invaluable subsurface information. Basic procedures that should be followed and the information obtained can form the basis for comparison for widely diverse sites and conditions. The following subparagraphs outline procedures and observations made and reported during coring operations. Examples for presenting core drilling data on ENG FORM 1836 are shown in Appendix D.

a. Drilling Observations. During the coring operation, a great deal of information is available about the subsurface conditions that may or may not be apparent in the core recovered from the hole. Observation of the drilling action must be made and reported to present as complete a picture, as possible, of the subsurface conditions.

(1) When coring with water as a circulating medium, the inspector should note the amount of water return relative to the amount being injected through the drill rods and its color. Careful observation of drill water return changes can indicate a potential zone where pressure test takes can be anticipated and correlated. Changes in the color of the return water can indicate stratigraphic changes and degrees of weathering such as clay-filled joints and cavity filling.

(2) When available, the hydraulic pressure being exerted by the drill should be recorded on each run as well as the fluid water pressure. While the drill is turning, the inspector should note and record the drill action (e.g., smooth or rough) and the rate of penetration. Rod drops, indicating open zones, should be recorded. Changes in drilling rate can be related to changes in composition and/or rock structure and in areas of poor core recovery, may provide the only indication of the subsurface conditions.

b. Procedural Information. Basic information to be included on each log regardless of the program undertaken is as follows: size and type of core bit and barrel used; bit changes; size, type and depth of casing, casing shoe and/or casing bit used; problems or observations made during placement of the casing; change in depth of casing setting during drilling; depth, length, and time for each run; amount of core actually recovered; and amount of core loss or gain.

4-13. Core Logging. Each feature logged shall be indicated or described in such a way that other persons looking at the core log will recognize what the feature is, the depth at which it occurred in the boring, and its thickness or size. They should also be able to obtain some idea of the appearance of the core and an indication of its physical characteristics. The log shall contain all the information obtainable from the core from a visual examination. Examples for presenting core logging data on ENG FORM 1836 are shown in Appendix D.

a. Rock Description. Each stratigraphic unit in the core shall be logged. The classification and description of each unit shall be as complete as possible. A recommended order of descriptions is as follows:

- Unit designation (Miami oolite, Clayton formation, Chattanooga shale).
- Rock type and lithology.
- Hardness.
- Degree of weathering.
- Texture.
- Structure.
- Color.
- Solution and void conditions.
- Swelling properties.
- Slaking properties.
- Additional descriptions such as mineralization, inclusions and fossils.

Criteria for these descriptive elements are contained in Table B-2 (Appendix B). Variation from the general description of the unit and features not included in the general description should be indicated at the depth and the interval in the core where the feature exists. These variations and features shall be identified by terms that will adequately describe the feature or variation so as to delineate it from the general description. They include zones or seams of different color and texture; staining; shale seams, gypsum seams, chert nodes and calcite masses; mineralized zones; vuggy zones; joints; fractures; open and/or stained bedding planes; faults, shear zones, and gouge; cavities, thickness, open or filled, and nature of filling and core left in the bottom of the hole after the final pull.

b. Solution and Void Conditions. Solution and void conditions shall be described in detail because these features can affect the strength of the rock and can indicate potential seepage paths through the rock. When cavities are detected by drill action, the depth to top and bottom of the cavity should be determined by measuring. Filling material, when present and recovered, should be described in detail opposite the cavity location on the log. When no material is recovered from the area of the cavity, the inspector should note the probable conditions of the cavity, as determined from observing the drilling action and the color of the drill fluid. If the drill action indicated material was present, i.e., slow rod drop, no loss of drill water, or noticeable change in color of water return, it should be noted on the log that the cavity was probably filled and the materials should be described as well as possible from the cuttings or traces left on the core. If drill action indicates the cavity was open, i.e., no resistance to the drill tools or loss of drill fluid, this should be noted on the drill log. By the same criteria, partially filled cavities should be noted. When possible, filling material should be preserved. During the field logging of the core at the drill site, spacers (ER 1110-1-1802) will be placed in the proper position in core boxes to show voids and losses.

c. Photographic Record. A color photographic record of all core samples should be made in accordance with ER 1110-1-1802. Photographs should be taken as soon as possible after retrieving the core samples. The core photographs can be reproduced on 8- by 10-in. prints, two or three core boxes to a photograph, and the photographic sheets can be placed in a loose-leaf binder for quick and easy reference. Photographs often enhance the logged description of cores particularly where rock defects are abundant. In the event that cores are lost or destroyed, the photographic record becomes the only direct, visual means for review of subsurface conditions without expensive redrilling to obtain new cores.

4-14. Drilling Log Form. All soil and rock drilling logs will be recorded using ENG FORM 1836 as the standard, official log of record. As a general rule, the depth scale on each sheet should be no smaller than 20 ft (i.e., not more than 20 ft of boring per sheet). Examples of completed drilling logs are shown in Appendix D.

4-15. Water Pressure Testing. Water pressure testing is discussed in Section VI, paragraph 4-22.

Section V. Borehole Examination

4-16. Borehole Viewing and Photography. The interpretation of subsurface conditions solely by observation, study, and testing of rock samples recovered from core borings often imposes an unnecessary limitation in obtaining the best possible picture of the 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 the structural features are required. Borehole viewing and photography equipment includes borescopes, photographic cameras, TV cameras, sonic imagery loggers, caliper loggers, and alinement survey devices. EP 1110-1-10 provides detailed information on TV and photographic systems, borescope, and televiewer. Sonic imagery and caliper loggers are discussed in detail in EM 1110-1-1802. Alinement survey services are available from commercial logging or drilling firms.

4-17. Borehole Camera and Borescope. Borehole cameras that have limited focus capability are satisfactory for examining bedrock features on the sidewalls of the borehole. However, the small viewing area and limited focus reduce their usefulness in borings that have caved or have cavities. They are best used for examining soft zones for which cores may not have been recovered in drilling and for determination of the dip and strike of important structural features of the rock formation. Borescopes have limited use because of their small viewing area, limited depth, and cumbersome operation but they are relatively inexpensive to use.

4-18. Borehole TV Camera and Sonic Imagery. The TV camera has variable focus and is suitable for examining the nature and approximate dimensions of caving sections of 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 the rock such as solution voids in calcareous formations, open cooling joints and lava tunnels in volcanic rocks, mines, tunnels, and shafts. The televiewer can be used to distinguish fractures, soft seams, cavities, and other discontinuities. Changes in lithology and porosity may also be distinguished.

4-19. Alinement Surveys. Alinement surveys are often necessary when the plumbness and/or orientation of a hole is important. 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 formation are required.

Section VI. Ground-water and Foundation Seepage Studies

4-20. General Investigation. The scope of ground-water studies is determined by the size and nature of the proposed project. The type of studies can range from broad regional studies at a reservoir project to site-specific studies such as pump tests for relief well design, or water supply at a recreational area, or pressure tests performed to evaluate the need for foundation grouting. Ground-water studies include observations and measurements of flows from springs and of water levels in existing wells, boreholes, selected observation wells, and piezometers. This information is used with site and regional geologic information to determine water table elevations and profiles, fluctuations in water table elevations, the possible existence and location of perched water tables, depths to probable water-bearing horizons, direction of seepage flow, and possible leakage from a proposed reservoir or beneath an embankment or levee. Complex investigations are made only after a thorough analysis has been made of existing or easily acquired data. Results from ground-water and foundation seepage studies provide data needed to design dewatering and seepage control systems at construction projects, indicate the potential for pollution and contamination of existing ground-water resources due to project operation, show potential for interference to aquifers by the construction of a project, and determine the chemical and biological quality of ground water and that relationship to project requirements.

a. Wells. Wells located during field geologic reconnaissance should be sounded, or water levels obtained from the well owners. Pumping quantities, seasonal variations in ground-water and pumping levels, depths of wells and screen elevations, corrosion problems, and any other relevant information should be acquired wherever available. Any settlement records attributable to ground-water lowering from pumping should be obtained. This information should be compared with water well records obtained during preliminary studies to develop a complete hydrologic picture for the project area.

b. Borings. Water levels recorded on drill logs are another source of information. However, they may not reflect true water levels, depending on soil types and time of reading after initial drilling. Loss of drilling fluids can indicate zones of high permeability. Where ground-water level information is needed, installation of piezometers or observation wells in borings should be considered.

c. Piezometers and Observations Wells. The most reliable means for determining ground-water levels is to install piezometers or observation wells. All information developed during preliminary studies on the regional ground-water regime should be considered in selecting locations for piezometers and observation wells. For types of piezometers, construction details, and sounding devices, refer to EM 1110-2-1908, Part 1, and TM 5-818-5/AFM 88-5, Chapter 6/NAVFAC P-418. All piezometer borings should be logged carefully.

d. Springs and Surface Water. The water elevation, flow rate, and temperature of all springs located within the project area should be measured. Samples should also be obtained for chemical analysis to establish a base line level. A description and classification of the soil or rock strata at the spring should be given for use in locating pervious strata. Flow rates at springs should be measured during dry and wet seasons to determine the influence of rainfall on changes in seepage conditions. The elevation of water levels in lakes and ponds should be measured during the dry season.

e. Geophysical Methods. Geophysical methods, such as seismic refraction, can be used to determine the depth to saturated material. Surface resistivity surveys can also indicate the presence of and depth to water.

4-21. Permeability Testing. Permeabilities of foundation materials can be determined from tests in piezometers and wells, pumping tests, and pressure tests in rock foundations. The permeability of sands can be roughly estimated from the D_{10} fraction (TM 5-818-5). Fracture and joint analysis is important in evaluating permeability of rock foundations.

a. Tests in Piezometers or Wells. Permeability tests can easily be made in piezometers or wells. They should be performed as part of piezometer installation procedures, both to obtain permeability information and to assure that the piezometer is working satisfactorily. Appropriate piezometer permeability tests are constant, falling or rising head, and slug tests. The information obtained is representative of a smaller volume of material than that tested in pumping tests. However, procedures are simple, costs are low, and results may be useful if interpreted with discretion. Test details are discussed in EM 1110-2-1908 (Part 1), TM 5-818-5, and items 4, 31, and 48.

b. Pumping Tests. Pumping tests are the traditional method for determining permeability of sand, gravels, or bedrock aquifers below the water table. Piezometers should be installed to measure the initial and lowered groundwater levels at various distances from the pumped well. For details of pumping tests and analyses, refer to TM 5-818-5. Pumping tests are usually desirable for the following:

- Large or complex projects requiring dewatering.
- Design of underseepage systems for dams or levees.
- Special aquifer studies.
- Projects where water supply will be obtained from wells.

c. Permeability of Rock. Most rock formations contain complex interconnecting systems of joints, fractures, bedding planes, and fault zones that, collectively, are capable of transmitting ground-water flow. This fracture or "joint permeability" is normally several magnitudes higher than the "matrix permeability" of the discrete blocks or masses of rock contained between the joints. The permeability of some rock masses, such as sandstones and conglomerates, is governed by interstitial voids similar to that of soils. Secondary weathering, solutioning, or formational processes in other rocks, such as limestones, breccias, and volcanic rocks, have produced large void spaces and exceptionally high permeabilities. While the permeability of rock is due to interconnecting systems of joints, fractures, and formational voids, the equivalent rock mass permeability can frequently be modeled as a uniform porous system.

d. Fracture and Joint Analysis. Since joint or fracture permeability frequently accounts for most of the flow of water through rocks, an accurate description of the in situ fracture condition of a rock mass is important in predicting performance of drains, wells, and piezometer responses. Such features as joint spacing, joint width, and the degree and type of secondary mineral filling should be noted carefully. The description can often be accomplished by developing the structure and stratigraphy of the site and locating accessible outcrops.

4-22. Pressure Tests. Pressure testing is performed to measure the permeability of rock masses. Pressure test results are used in assessing leakage in the foundation and as a guide in estimating grouting requirements. Pressure tests are usually conducted during exploratory core drilling and are a relatively inexpensive method of obtaining important, hydrogeologic information about a rock mass. Hydraulic pressure testing should be considered an integral part of the exploratory core drilling process in all cases where rock seepage characteristics could affect project safety, feasibility, or economy. The testing interval is typically 5 to 10 ft but may be varied to fit specific geological conditions observed during the core drilling operations. Zones to be tested should be determined by (a) examining freshly extracted cores, (b) noting depths where drill water was lost or gained, (c) noting drill rod drop, (d) performing borehole or TV camera surveys, and (e) conducting downhole geophysical surveys. In rock with vertical or high angle joints, inclined borings are necessary to obtain meaningful results. Types of tests and test procedures are described in items 5, 48, and 52.

a. Pressures applied to the test section during tests should normally be limited to 1 psi/ft of depth above the piezometric level and 0.57 psi/ft of depth below the piezometric level. The limit was established to avoid jacking and damage to rock formations. The limit is conservative for massive igneous and metamorphic rocks. However, it should be closely adhered to for tests in horizontally bedded sedimentary and other similar types of formations. Naturally occurring excess water pressures (artesian) should be taken into account in computations for limiting test pressures. Where the test intervals are large, a reduction in total pressure may be necessary to prevent jacking of the formation within the upper portion of the test section.

b. An important but often unrecognized phenomenon in pressure testing is joint dilation and contraction as pressure is applied and released. In the case of a dam project, it is desirable to use pressures that will correspond to future reservoir conditions. Joint dilation can frequently be observed by conducting a "holding" test. The fall in pressure is observed and a plot of pressure versus time is made. The pressure should quickly drop to near the surrounding piezometric level if the joint openings remain the same width. The common observation of a slow pressure decay in pressure holding tests indicates joint closure with reduction in pressure.

c. Qualitative evaluations of leakage and grout requirements can be made from raw pressure test data (items 5, 48, and 52). Most analyses of this type assume laminar flow rather than turbulent flow. This assumption can be verified by conducting pressure tests on the same interval at several different pressures. When the water take is directly proportional to the total applied pressure, laminar flow can be assumed. When pressure test data are converted into values of equivalent permeability or transmissivity, calculations can be performed to estimate seepage quantities. Whenever possible, such results should be compared with data from completed projects where similar geologic conditions exist.

Section VII. Exploratory Excavations

4-23. Test Pits and Trenches. Test pits and trenches can be constructed quickly and economically by bulldozers, backhoes, pans, draglines, or ditching machines. Depths generally are less than 20 to 30 ft, and sides may require shoring if personnel must work in the excavations. Final excavation to grade where samples are to be obtained or in situ tests performed must be done carefully. Test pits and trenches generally are used only above the ground-water level. Exploratory trench excavations are often used in fault evaluation studies. An extension of a bedrock fault into much younger overburden materials exposed by trenching is usually considered proof of recent fault activity. Shallow test pits are commonly used for economical borrow area explorations.

4-24. Exploratory Tunnels. Exploratory tunnels permit detailed examination of the composition and geometry of rock structures such as joints fractures, faults, shear zones, and solution channels. They are commonly used to explore conditions at the locations of large underground excavations and the foundations and abutments for large dam projects. They are particularly appropriate in defining the extent of marginal strength rock or adverse rock structure suspected from surface mapping and boring information. For major projects where high-intensity loads will be transmitted to foundations or abutments, tunnels afford the only practical means for testing in-place rock at locations and in directions corresponding to the structural loading.

a. In the case of planned underground construction, an exploratory tunnel is often used to gain access to crown and roof sections of future large underground excavations. The tunnel can then be used during construction for equipment access and removal of excavated rock. A small bore or exploratory "pilot" tunnel is sometimes driven along the entire length of a proposed larger diameter tunnel where difficult and often unpredictable ground conditions are anticipated. A pilot tunnel may be the most feasible alternative for long deep tunnels where deep exploratory drilling and access for in situ testing from the ground surface is prohibitively expensive. The pilot tunnel can be positioned to allow installation of roof support for critical areas of the full tunnel, or in some cases, to provide relief or "burn cuts" to facilitate blasting. When exploratory tunnels are strategically located, they often can be incorporated into the permanent structure. They can be used for drainage and postconstruction observations to determine seepage quantities and to confirm certain design assumptions. On nonwater-related projects, exploratory tunnels may be used for permanent access or for utility conduits.

b. The detailed geology of exploratory tunnels, regardless of their purpose, should be mapped in accordance with the procedures outlined in Appendix C. The cost of obtaining an accurate and reliable geologic map of a tunnel is usually insignificant compared with the cost of the tunnel and support system. The geologic information gained from such mapping provides a very useful additional dimension to interpretations of rock structure deduced from exposures in surface outcrops. A complete picture of the site geology can be achieved only when the geologic data and interpretations from surface mapping, borings, and pilot tunnels are combined and well correlated.

Section VIII. In Situ Testing for Determining Geotechnical Properties

4-25. General. 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. Table 4-4 lists in situ tests and their purposes. In situ rock tests are performed to determine in situ stresses and deformation properties of the jointed rock mass, shear strength of jointed rock masses or critically weak seams within the rock mass, and residual stresses along discontinuities

Table 4-4. In Situ Tests

Purpose of Test	Type of Test	Applicability to Soil	Applicability to Rock
Shear strength	Standard penetration test (SPT)	X	
	Field vane shear	X	X
	Cone penetrometer test (CPT)	X	
	Direct shear	X	
	Plate bearing or jacking	X	X[a]
	Borehole direct shear[b]	X	
	Pressuremeter[b]		X
	Uniaxial compressive[b]		X
	Borehole jacking[b]		X
Bearing capacity	Plate bearing	X	X[a]
	Standard penetration	X	
Stress conditions	Hydraulic fracturing	X	X
	Pressuremeter	X	X[a]
	Overcoring		X
	Flatjack		X
	Uniaxial (tunnel) jacking	X	X
	Borehole jacking[b]		X
	Chamber (gallery) pressure[b]		X
Mass deformability	Geophysical (refraction)	X	X
	Pressuremeter or dilatometer	X	X[a]
	Plate bearing	X	X
	Standard penetration	X	
	Uniaxial (tunnel) jacking	X	X
	Borehole jacking[b]		X
	Chamber (gallery) pressure[b]		X
Relative density	Standard penetration	X	
	In situ sampling	X	
	Dutch cone[b]	X	
Liquefaction susceptibility	Standard penetration	X	
	Cone penetrometer test (CPT)[b]	X	

[a] Primarily for clay shales, badly decomposed, or moderately soft rocks, and rock with soft seams.

[b] Less frequently used.

or weak seams in the rock mass. Pressure tests have been discussed in Section VI (para 4-20).

a. Soils, Clay Shales, and Moisture-Sensitive Rocks. Interpretation of in situ tests in soils, clay shales, and moisture-sensitive rocks requires consideration of the drainage that may occur during the test. Consolidation during testing makes it difficult to determine whether the test results correspond to unconsolidated-undrained, consolidated-undrained, consolidated-drained conditions, or intermediate conditions between these limiting states. The cone penetrometer test (CPT) is very useful for detecting soft or weak layers and in quantifying undrained strength trends with depth. Interpretation of in situ test results requires a complete evaluation of the test conditions and the limitations of the test procedure.

b. Rock. Rock formations are generally separated by natural joints and fractures into a system of irregularly-shaped blocks that respond as a discontinuum when subjected to various loading conditions. The response of a jointed rock mass to imposed loads involves a complex interaction of compression, sliding, wedging, rotation, and possibly fracturing of individual rock blocks. Individual blocks generally have relatively high strengths, while the strength along discontinuities is normally reduced and highly anisotropic. Frequently, little or no tensile strength exists across discontinuities. As a result, resolution of forces within the system generally cannot be accomplished by ordinary analytical methods. Large-scale in situ tests tend to average out the effect of complex interactions. In situ tests in rock are frequently expensive and should be reserved for projects with large, concentrated loads. Well conducted tests may be useful in reducing overly conservative assumptions. Such tests should be located in the same general area as a proposed structure and test loading should be applied in the same direction as the proposed structural loading.

4-26. In Situ Tests to Determine Shear Strength. Table 4-5 lists in situ tests that are useful for determining the shear strength of subsurface materials.

a. The Standard Penetration Test (SPT). The SPT is useful for preliminary appraisals of a site. The N-value has been empirically correlated with liquefaction susceptibility under seismic loadings (item 38). The N-value is also useful for pile design. In cohesive soils, the N-value can be used to determine where undisturbed samples should be obtained. The N-value can also be used to estimate the bearing capacity (items 28 and 34) and the unconfined compressive strength (item 31) of soils.

b. Direct Shear Tests. In situ direct shear tests are expensive and are performed only where doubt exists about available shear strength

Table 4-5. In Situ Tests to Determine Shear Strength

Test	For Soils	For Rocks	Reference	Remarks
Standard penetration	X		EM 1110-2-1907, Appendix C	Use as index test only for strength. Develop local correlations. Unconfined compressive strength in tsf is often 1/6 to 1/8 of N-value
Direct shear	X	X	RTH[a] 321	Expensive; use when representative undisturbed samples cannot be obtained
Field vane shear	X		EM 1110-2-1907, Appendix D	Use strength reduction factor
Plate bearing	X	X	ASTM[b] Designation D 1194 ASTM STP 479[c]	Evaluate consolidation effects that may occur during test
Uniaxial compression		X	RTH[a] 324	Primarily for weak rock; expensive since several sizes of specimens must be tested
Cone penetrometer test (CPT)			Items 40 and 22	Consolidated undrained strength of clays; requires estimate of bearing factor, N_c

[a] Rock Testing Handbook.

[b] American Society for Testing and Materials.

[c] Special Technical Publication 479.

data and where thin, soft, continuous layers exist within strong adjacent materials. The direct shear test measures peak and residual strength as a function of stress normal to the shear plane. Results are usually employed in limiting equilibrium analysis of slope stability problems or for stability analysis of foundations for large structures such as dams. When field evidence suggests that only residual strengths can be relied on, either in a thin layer or in a mass, because of jointing, slickensiding, or old shear surfaces, in situ direct shear tests may be necessary. Few in situ direct shear tests are performed on soils, but they may be justified on clay shales, indurated clays, very soft rock, and thin, continuous, weak seams that are difficult to sample. Methods for performing in situ strength tests on rock are described in item 51.

c. Field Vane Shear Tests. Field vane tests performed in boreholes can be useful in soft, sensitive clays that are difficult to sample. However, they sometimes give results that are too high. Factors to correct the results are discussed in items 8 and 31.

d. Plate Bearing Tests. Plate bearing tests can be made on soil or soft rock. Because of their cost, such tests are normally performed during advanced design studies or during construction. They are used to determine subgrade moduli and occasionally to determine strength.

e. Cone Penetrometer Test and Dutch Cone. The Cone Penetrometer Test (CPT) can provide detailed information on soil stratigraphy and preliminary estimations of geotechnical properties. Based on the soil type as determined by the CPT (item 12) or adjacent boring, the undrained strength can be estimated for clays (items 40 and 22), and the relative density (and friction angle) estimated for sands (items 41, 13, and 30). For clays, a bearing factor, N_c , must be estimated in order to calculate the undrained strength from the CPT cone resistance and should be close or slightly greater than the CPT sleeve friction resistance if the soil is not sensitive or remolded (item 12). The calculated undrained strength as well as the change of undrained strength with depth can both be used with several techniques to estimate the overconsolidation ratio (OCR) (item 40). For sands, the relative density can be estimated if the overconsolidation conditions (i.e., lateral stress ratio) and vertical effective stress are known. The friction angle can also be estimated but also depends on the cone surface roughness and the assumed failure surface shape (item 13). The mechanical (i.e., Dutch) cone is performed at a depth interval of 8 in. using hydraulic gages which measure the force from an inner rod directly in contact with the end of the probe. The electric (PQS or FUGRO) cone is pushed at a constant speed for 1 meter intervals while electronically measuring cone and friction resistance continuously.

4-27. In Situ Tests to Determine Stress. Table 4-6 lists the field tests that can be used to determine in situ stress conditions. The results are used in finite element analyses, estimating loading on tunnels, and determining rock burst susceptibility in excavations, as well as identifying regional active and residual stresses. Stresses occur as a result of gravity forces, actively applied geologic forces such as regional tectonics, and from stored residual-strain energy. Stress is measured in order to determine the effect on foundations from changes in loading due to excavation or construction. Where confinement of a material has been removed by natural means or by excavation, the remaining material tends to approach a residual state of stress. In a majority of projects the major principal stress is vertical, i.e., the weight of the overlying material. However, it has been found from measurements made throughout the world that horizontal stresses in the near surface area, defined as 100 ft (30.48 m) or less, can be 1.5 to 3 times higher than the vertical stress. Recognition of this condition during the design phase of investigations is very important. Whenever high horizontal stresses exist at a project site, the stability of cut slopes and tunnel excavations is affected. In situ testing is the most reliable method for obtaining the magnitude and direction of stresses. The three most common methods for determining in situ stresses are the overcoring, hydrofracture, and flatjack techniques.

a. Overcoring Method. Possibly the most common method used for measuring in situ stresses in rock is overcoring. A NW core hole is drilled, instrumented, and redrilled with a larger core barrel. The overcoring decouples the rock surrounding the instrument package from the natural stress field of the in-place formation. The change in strain recorded by the instruments is then converted to stress by using the elastic modulus of the rock determined from laboratory tests. At least three separate tests must be made in the rock mass in nonparallel boreholes. A detailed description of the field test is given in the Rock Testing Handbook (RTH 341). The overcoring method is hampered by many instrument lead wires, which may be broken during testing. The practical maximum depth of testing is usually less than 150 ft.

b. Flatjack Method. In the flatjack method, two points are inscribed on the rock walls of a tunnel. A slot is bored or cut into the rock wall midway between the inscribed points. Stresses present in the rock will tend to partially close the slot. A hydraulic flatjack is then inserted in the slot, and the rock jacked back to its original position as determined by the inscribed points. The unit pressure required is a measure of the in situ stress. The value recorded must be corrected for the influence of the tunnel excavation itself. Flatjack tests obviously need an excavation or tunnel for the test. The high cost for constructing the opening usually precludes this technique as an indexing tool except where the size of the structure and complexity of the site dictates its use.

Table 4-6. In Situ Tests to Determine Stress Conditions

Test	Soils	Rocks	Bibliographic Reference	Remarks
Hydraulic fracturing	X		Items 24 and 31	Only for normally consolidated or slightly consolidated soils
Hydraulic fracturing		X	RTH[a] 344 Items 18 and 20	Stress measurements in deep holes for tunnels
Vane shear	X		Item 7	Only for recently compacted clays, silts, and fine sand (see item 7 for details and limitations)
Overcoring techniques		X	RTH 341 Items 18 and 37	Usually limited to shallow depth in rock
Flatjacks		X	RTH 343 Items 11 and 18	
Uniaxial (tunnel) jacking	X	X	RTH 365	May be useful for measuring lateral stresses in clay shales and rocks, also in soils

[a] Rock Testing Handbook.

c. Hydrofracture Method. The hydrofracture method has been used in soils and rock. A section of hole is isolated with packers at depth, and an increasingly higher water pressure applied to the zone. A point will be reached where the pressure begins to level off, and there is a marked increase in water take. This indicates that a crack in the formation has opened, and the threshold pressure has been reached. The threshold pressure is an indication of the minor principal stress. The orientation is then obtained by an impression packer. This procedure then gives the intensity and direction of the minor principal stress, which is perpendicular to the crack. The hydrofracture method has no particular depth limitation, but the drilling of deep holes can be very expensive. This expense can often be circumvented by using holes that have been drilled for other purposes. Recent evidence has indicated that stresses measured within 100 ft or more of ground surface may not always reflect the actual stress magnitude or orientation at depth. This may be true particularly in areas where closely jointed and weathered surface rock formations are decoupled from the deeper, more intact rock.

4-28. 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, static design of concrete gravity and arch dams, tunnels, and certain military projects. Geotechnical investigations for such purposes should be planned jointly by geotechnical and structural engineers. Deformation properties are normally expressed in terms of three interdependent parameters: Young's modulus, shear modulus, and Poisson's ratio. These parameters are valid only for materials that are linear, elastic, homogeneous, and isotropic. In spite of this limitation, these parameters are often used to describe the deformation properties of soil and rock. Large-scale tests (e.g., tunnel jacking) are frequently used since they reduce the effect of nonhomogeneity. Multiple tests, with different orientations, can be used to determine the anisotropy of the deformation properties. Soils, in particular, tend to be nonlinear and inelastic. As a result, their properties are often strain dependent, i.e., moduli determined at low strain levels can be substantially different from those determined at high strain levels. The fact that sample disturbance, particularly in soils, can substantially affect the deformation properties serves as the primary reason for using in situ tests in soils. Table 4-7 lists the in situ tests used to determine one or more of the deformation parameters. Some test results are difficult to relate to the fundamental parameters but are used directly in empirical relationships (table 4-8). Deformation properties of a jointed rock mass are very important when highly concentrated loadings are directed into the abutments of arch dams in directions that are tangent to the arches at the abutments. In these cases, the ratio of the deformation modulus of the abutment rock to that of the concrete in the dam must not be so low as to cause adverse tensile stresses to develop within the concrete dam. One problem often encountered in conducting in situ deformation tests is the need to

Table 4-7. In Situ Tests to Determine Deformation Characteristics

Test	For Soils	For Rocks	Reference	Remarks
Geophysical refraction, crosshole, and downhole	X	X	EM 1110-1-1802	For determining dynamic Young's Modulus, E , at the small strain induced by test procedure. Test values for E must be reduced to values corresponding to strain levels induced by structure or seismic loads
Pressuremeter	X	X	RTH[a] 362 Items 1 and 31	Consider test as possibly useful but not fully evaluated. For soils and soft rocks, shales, etc
Chamber test	X	X	Items 19 and 42	
Uniaxial (tunnel) jacking	X	X	RTH 365 Item 42	
Flatjacking		X	RTH 343 Items 11 and 18	
Borehole jack or dilatometer		X	RTH 363 Item 42	
Plate bearing		X	RTH 364 ASTM[b] STP 479 Item 42	
Plate bearing	X		MIL-STD 621A, Method 104	
Standard penetration	X		Item 19, pages 34 and 35	Correlation with static or effective shear modulus, in psi, of sands; settlement of footings on clay. Static shear modulus of sand is approximately: $G_{eff} = 1960N^{0.51}$ in psi; N is SPT value

[a] Rock Testing Handbook.
[b] American Society for Testing and Materials, Special Technical Publication 479.

Table 4-8. Correlations Between Field Tests for Soils, Material Characteristics, and Structural Behavior

Field Test	Correlation With	Remarks
1 x 1-ft Plate load test	Modulus of subgrade reaction. Settlement of footings on sand	Item 31
Load test for radar towers	Young's modulus of subgrade soils	MIL-STD-621A
Standard penetration N-value	Settlement of footings and mats on sand; shear modulus	TM 5-818-1 Items 19, 28, 34, and 47
Cone penetrometer test	ϕ of sands; settlement of footings on sand; relative density	Items 31, 29, 41, and 13 Item 39 Items 40 and 41

include representative sizes of the jointed rock mass in the test, particularly when the joint spacing is moderately large (e.g., 2 to 3 ft). This problem has been solved in some instances by excavating a chamber in rock, lining it with an impermeable membrane, and subjecting it to hydraulic pressure to load the rock over relatively large areas.

a. Chamber Tests. Chamber tests are performed in large, underground openings. Generally these openings are test excavations such as exploratory tunnels. Pre-existing openings, such as caves or mine chambers, can be used if available and applicable to project conditions. The opening is lined with an impermeable membrane and subjected to hydraulic pressure. Instrumented diametrical gages are used to record increases in tunnel diameter as the pressure load increases. The test is performed through several load-unload cycles. The data are subsequently analyzed to develop load-deformation curves from which a deformation modulus can be selected.

b. Uniaxial Jacking Test. An alternative to chamber tests is the tunnel jacking test performed by the Bureau of Reclamation and others (Rock Testing Handbook (RTH 365)). The test uses a set of diametrically opposed jacks to test larger zones of rock. This method produces nearly comparable results with chamber tests without incurring the much greater expense. The test determines how foundation rock will react to controlled loading and unloading cycles and provides data on deformation moduli, creep, and rebound. Jacking tests are the preferred method for determining deformation properties of rock masses for large projects.

c. Other Deformation Tests. Other methods for measuring the deformation properties of in situ rock are anchored cable pull tests, flatjack tests, borehole jacking tests, and tunnel jacking tests. The anchored cable pull test uses cables, anchored at depth in boreholes, to provide a reaction to large slabs or beams on the surface of the rock. The test is expensive and difficult to define mathematically, but offers the advantages of reduced shearing strains and larger volumes of rock being incorporated in the test. Flatjack tests are flexible and numerous configurations may be adopted. In relation to other deformation tests, the flatjack test is relatively inexpensive and useful when direct access is available to the rock face. Limitations to the method involve the relatively small volume of rock tested and difficulty in defining a model for calculation of deformation or failure parameters. The borehole jack ("Goodman" jack) or dilatometer have the primary advantage that direct access to the rock face is not required. The development of a mathematical model for the methods, however, has proved to be more difficult than with most deformation measurement techniques. Radial tunnel jacking tests are similar in principle to the borehole jacking tests except that larger volumes of rock are involved in the testing. Typically, steel rings are placed within a tunnel with flatjacks placed between the rings and the tunnel surfaces. The tunnel is loaded radially and deformations are measured. The method is expensive but useful, and is in the same category as chamber tests. All methods of deformation measurements have inherent advantages and disadvantages, thus selection of test methods must be dictated by the nature of the rock mass, the purpose of the test, and the magnitude of the project. Care must be exercised and limitations recognized in the interpretation and use of measurements of deformation.

4-29. Determination of Dynamic Moduli by Seismic Methods. Seismic methods, both downhole and surface, are used on occasion to determine in-place moduli of rock. The compressional wave velocity is mathematically combined with the rock's mass density to estimate a dynamic Young's modulus, and the shear wave velocity is similarly used to estimate the dynamic rigidity modulus. However, since rock particle displacement is so small and loading transitory during these seismic tests, the resulting modulus values are nearly always too high. The seismic method of measuring 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 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 the strain levels increase, the shear modulus and Young's modulus decrease and the damping increases. Consideration of these factors is necessary when performing earthquake analyses.

4-30. Empirical Correlations for Soils. Table 4-8 presents some empirical correlations between in situ tests for soils and material properties and structure behavior. These correlations may be useful for small structures but should not be used for design of major structures. For more information regarding such correlations for building design, refer to TM 5-818-1.

Section IX. Backfilling of Holes and Disposition of Samples and Cores

4-31. Backfilling Boreholes and Exploratory Excavations. Except where the hole is being preserved for future use, all boreholes and exploratory excavations will be backfilled. The reasons for backfilling holes are: to eliminate safety hazards for personnel and animals, to prevent ground-water pollution or the contamination of aquifers, to minimize underseepage problems of dams and levees, and to minimize adverse environmental impacts. Holes preserved for the installation of instrumentation, borehole examination, or downhole geophysical work should be backfilled when no longer needed. As a minimum, borings that are preserved for future use should be protected with a short section of surface casing, capped, 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. Backfilling boreholes and exploratory excavations are discussed further in EM 1110-2-1907, Chapter VIII.

4-32. Disposition of Soil Samples. Soil samples may be discarded once the testing program for which they were taken is complete. Soil samples are not normally retained for long periods because even the most careful sealing and storing procedures cannot prevent the physical and chemical changes that, in time, would invalidate any subsequent test results. The requirements for the disposition of soil samples from plant pest quarantined areas are specified in ER 1110-1-5.

4-33. Disposition of Rock Cores. All exploratory and other cores not used for test purposes shall be properly preserved, boxed, and stored in a protected storage facility until disposal. The following procedures govern the ultimate disposition of the cores in accordance with ER 1110-1-1803.

a. Care and Storage. Exploratory or other cores, regardless of age, will be retained until the detailed logs, photographs, and test data have been made a matter of permanent record. Precautions shall be taken to insure against the disposal, destruction, or loss of cores that may have a bearing on any unsettled claim. Such cores shall be retained until final settlement of all obligations and claims. They then will be disposed of in accordance with the procedures outlined in b below.

b. Disposal. Cores over 6 in. in diameter may be discarded after they have served their special purpose. In a case where the project is deauthorized, all cores pertaining thereto may be discarded. When a project has been completed and final settlement has been made with the contractors and others concerned, all cores, except those related to future construction, and a few selected cores representative of foundation and abutment conditions, may be discarded. Selected cores, retained after the completion of a project, and additions thereto, may be discarded or otherwise disposed of 5 years after final completion of the project, provided no unforeseen foundation or abutment conditions have developed. After cores are disposed of, core boxes shall be salvaged for reuse if their condition permits; otherwise, they may be discarded.

Section X. Test Grouting

4-34. Purpose. Test grouting operations are usually performed at projects where complex geological conditions or unusually severe project requirements make it necessary to acquire a knowledge of grouting performance prior to the letting of major contracts. Test grouting consists of performing experimental grouting operations on exploratory boreholes to determine the extent to which the subsurface materials are groutable. A well conducted grout program can provide cost-effective data for the preparation of contract plans and specifications. This can reduce the potential for construction claims. Grouting procedures which are necessary for development of a satisfactory test grouting program are discussed in detail in TM 5-818-6 and EM 1110-2-3501, -3503 and -3504.

4-35. Testing Practices. In test grouting, the methods used should be guided by the geologic conditions at the site. For example, stage grouting is preferable in rock formations where joint permeability prevails and the weight of increasing overburden with depth tends to close and tighten joint passageways. In solutioned limestone formations or pervious lava flows, major water passageways may not decrease in size with depth. Consequently, stop grouting is preferable since this procedure is initially directed at the source of water seepage.

4-36. Testing Program. A test grouting program is nearly always performed in a small area. Where the ground-water table is located in the limits of the curtain, it may be necessary to construct the grout curtains in closed circular or rectangular arrays. In this manner, the effectiveness of the grout curtain can be evaluated by performing pumping tests before and after grouting. The well is usually located at the center of the grout curtain enclosure. Observation wells are positioned to radiate from one or more directions outward from the well, and through the test curtain. A comparison of the reduction of water pumped from the well before and after grouting is a direct measure of the efficiency of the grout curtain. Where the water table is low or nonexistent, a multiple, linearly aligned curtain is sufficient for test purposes. Comparison of pre- and postgrouting pressure tests should be made to evaluate the effectiveness of the test grouting schemes. Some of the important variables a test grouting program should resolve are basic grouting methods, hole spacing, grout consistency and additives, and injection pressures. Some projects may require the testing and applicability of using chemical grout to solve difficult seepage or foundation competency problems.

Section XI. Test Quarries and Test Fills

4-37. Test Quarries. Test quarries are usually conducted in conjunction with test fill programs and in areas where large quantities of rock material will be needed from undeveloped sources. Test quarries are especially important where there are serious questions about the suitability of rock in required excavations for use in embankment rock-fill zones or for slope protection. In addition to providing material for rock test fills, test quarries provide information on cut slope design constraints resulting from adverse geologic structure, suitable blasting techniques, suitability of quarry run rock, and the feasibility and best methods for processing materials. The results of quarry tests can provide designers and prospective bidders with a much better understanding of drilling and blasting characteristics of the rock. Although useful information is gained from a well conducted test quarry program, it is an expensive type of "exploration." Whenever possible, a test quarry should be located in an area of required excavation. Excess materials from the test quarry can be stockpiled for later use. Determining the optimum methods of precision slope development (e.g., best presplitting blasthole spacing and powder factors) can be an important part of the test quarry program. This determination insures maximum side slope stability by minimizing overbreakage. Mapping of test quarry slopes can provide needed geologic data for use in design of permanent slopes. To be of maximum benefit, the test quarry should be located in a portion of the excavation area that is representative of the geologic conditions to be encountered.

a. Geologic Study. Before a test quarry program is undertaken, a careful geologic study should be made of the test quarry site. The geologic study should include:

(1) Field reconnaissance and mapping of exposed rock jointing and discontinuities.

(2) Examination of boring logs, rock cores, and borehole survey results to determine depth of overburden and weathered rock, joint patterns, presence of filled solution joints or fault zones, and groundwater conditions that could affect blasting operations.

(3) Consideration of regional stress fields and site-specific stress conditions that could affect stress relief in joints during quarrying operations.

(4) Development of geologic sections and profiles depicting rock type and stratum thickness, joint spacing, frequency and orientation, filled joint systems, and other discontinuities that would influence rock breakage and the amount of fines.

(5) Consideration of all other factors that may control size, quantity, and quality of blasted rock (e.g., proximity to structures or urban areas where blast size, airblast, ground vibrations, or fly rock may have to be rigidly controlled).

b. Test Objectives. Once geologic studies indicate that a quarry source can produce adequate quantities and the upper size desired, other data needed for test quarry design purposes include overall gradation, yield, quality, and production. Blasting techniques and modifications to fit geologic conditions are discussed in Chapters 5 and 6 of EM 1110-2-3800. The upper fragment size is determined by the geologic conditions and rock structure. Other sizes and gradations can be controlled partially by the blasting techniques. If smaller rock sizes are needed, increased fragmentation may be achieved by the following:

- Increasing the powder factor.
- Decreasing blasthole spacing and corresponding burden ratios.
- Using millisecond delays.
- Using faster powder.
- Employing satellite blastholes.
- Adjusting blasting patterns.

c. Test Program. In a well planned test quarry program, many of the blasting variables listed in b above are subjected to field experimentation. The program should be developed and supervised by an experienced geologist or geotechnical engineer. By dividing the test quarry into separate tests, each of the variables can be evaluated separately while the others are held constant. For each test, the blasted rock must be gathered, sieved, and weighed to obtain gradations. For aggregate studies, representative samples should be taken for processing, testing, and mix design. When blasted rock is also being used for rock test fills, it may be necessary to use representative truck loads for gradation processing. As individual test blasts are completed and gradations determined, modifications to the blasting technique can be made. When all individual test blasts and associated gradations are completed, the data should be reviewed to determine which set of blasting parameters best fulfills design requirements. Test quarry programs are discussed in items 3, 5, and 26.

d. Application. The results of test quarry programs are expressed in terms of optimum blasting patterns, powder factors, blasthole sizes, firing delay sequences, yields, and gradations. When these results are combined with results of test fills, they form a valuable source of data for the designer. This information is equally valuable to prospective contractors and should be included in the plans and specifications.

4-38. Test Fills and Trial Embankments.

a. Test Fills. Test fills are usually recommended only where unusual soils or rockfill materials are to be compacted or if newly developed and unproven compaction equipment is to be employed. However, test fills are valuable for training earthwork inspectors on large projects, especially if materials vary widely or if compaction control procedures are complex. Test fills constructed solely to evaluate new or different compaction equipment are ordinarily performed by the contractor at his expense. Rock test fills are most frequently required simply to determine optimum placement and compaction operations. Test quarries are often associated with a rock test fill program to determine blasting requirements and to establish any required preplacement material processing. Test fills must be constructed ahead of contract advertisement as they are necessary to establish specifications. It is most economical if such test fills can be located in low stressed regions of the embankment and incorporated within the final embankment section. If cofferdams of compacted fill are required on the project, these can be utilized as test fills but only if their serviceability is not affected. In the past, Corps of Engineers Districts have found it most satisfactory to construct precontract test fills themselves by renting the necessary equipment or even letting a separate contract. The following two considerations are most important in execution of a test fill program:

(1) Plan of Tests. Usually several different parameters are to be evaluated from a test fill program. Therefore, the test program should be thoroughly planned so that each parameter is properly isolated for evaluation. All aspects of the program must be treated in detail, particularly the means of measurements and controls and data reduction.

(2) Representative Materials and Procedures. The test fill operations must be representative with regard to prototype materials and placement and compaction procedures. This is especially critical in rock test fill programs associated with test quarries. For additional information, see item 21 and EM 1110-2-1911.

b. Trial Embankments. Trial embankments are infrequently used but may be the only reliable means for resolving uncertainties about the probable behavior of complex subsurface conditions or of poor quality embankment materials. (Trial embankments were constructed, for example, at Laneport, Warm Springs, and R. D. Bailey Dams.)

(1) Where subsurface shear strengths are so low that the gain in strength from consolidation during construction must be relied upon, or if it is economical to do so, a trial embankment is desirable, especially where long embankments are to be constructed. A trial embankment affords the most reliable means for determining the field rate of consolidation and efficacy of means to accelerate consolidation.

(2) Clay shale foundations are often jointed and slickensided, and may contain continuous relict shear surfaces. Laboratory shear tests on undisturbed samples generally give too high shear strengths and may be badly misleading. The in situ mass strength of clay shales can best and frequently can only be determined by analyzing existing slopes or constructing trial embankments. When trial embankments are incorporated within the final section, their height and slopes must be designed to result in desired shear stresses in the foundation. Where natural slopes are flat, suggesting that residual shear strengths govern stability of slopes and cuts, trial embankments can be useful in resolving uncertainties about available shear strengths; i.e., are natural slopes flat because residual shear strengths have developed or because of natural erosion processes and a mature landscape?

(3) If special circumstances indicate the desirability of using wet, soft clay borrow that cannot economically be reduced to conventional compaction water contents, a trial embankment should be strongly considered.

CHAPTER 5
LABORATORY INVESTIGATIONS

5-1. General. The purposes of laboratory tests are to investigate the physical and hydrological properties of natural materials such as soil and rock, determine index values for identification and correlation by means of classification tests, and define the engineering properties in parameters usable for design of foundations. The geotechnical engineer, using the test data and calling upon his experience, can then accomplish safe and economical designs for engineering structures. Chapter 5 is divided into four sections that discuss index and classification tests, engineering properties of soil, engineering properties of rock, and engineering properties of shales and moisture-sensitive rocks. No attempt has been made to describe the techniques for performing individual tests; references are provided for that purpose. A wide range of soil and rock tests are identified, and the appropriate application is discussed.

Section I. Test and Sample Selection

5-2. General. The selection of samples and the number and type of tests are largely influenced by local subsurface conditions and the size and type of structure. Table 5-1 lists references that provide guidance for assigning laboratory tests for various types of structures. As a minimum, all soil samples should be classified according to the Unified Soil Classification System (USCS) (see para 4-10), and moisture contents determined on cohesive soils, as well as on granular soils from above the water table which have 12 percent or more fines. Rock cores should be visually classified and logged prior to any laboratory testing. The geologic model (para 3-1 and 3-8) can be further developed using the results of basic indexing of soils and rock cores, together with other geotechnical data obtained from field reconnaissance and preliminary investigations. The geologic model, in the form of profiles and sections, can be used to indicate where additional indexing of soils and rock is needed, as well as the type and number of tests required to determine the engineering properties of all materials influencing the project. As more data become available, the testing requirements should be reviewed and modified as necessary.

a. Selection of Samples for Testing. Most index testing of soil and rock is performed on disturbed samples, i.e., samples that have not had special handling to preserve structural integrity. However, in order to determine natural water content the sample must be protected from drying. For soils, protection can be accomplished by using sealed metal tubes or glass jars. For rock, the samples are normally waxed to prevent drying. Since many laboratory tests, particularly those to determine engineering properties, require "undisturbed" samples, great

Table 5-1. Guidance for Assigning Laboratory Tests

Type of Structure or Work	Reference
Embankment dams	EM 1110-2-2300 EM 1110-2-1902
Concrete gravity dams	EM 1110-2-2300[a] EM 1110-2-1902[a]
Buildings and other structures	TM 5-818-1
Deep excavations	TM 5-818-5/AFM 88-5, Chapter 6/NAVFAC P-418
Tunnels and shafts in rocks	EM 1110-2-2901
Breakwaters	EM 1110-2-2904
Pile structures and foundations	EM 1110-2-2906
Levees	EM 1110-2-1913

[a] For general guidance, item 33 provides additional information.

care must be exercised in selecting, shipping, and preparing these materials. The geologist and/or geotechnical engineer responsible for applying test data to project requirements should have positive control of sampling and shipping soil and rock samples, as well as responsibility for the entire cycle. Table 5-2 lists some of the factors that may cause undisturbed samples to be less representative of the conditions encountered on the project.

b. Distribution and Size of Samples. The distribution of soil and rock tests should be evaluated periodically. Within the project requirements, a suitable suite of index and engineering property tests should be planned both in a vertical as well as a lateral direction. Duplication of costly, complex tests should be avoided except where statistical balance is required. If it becomes apparent in the application of the test data that coverage of field conditions is irregular, or missing in certain stratigraphic units, the field sampling procedures should be revised or modified. Undisturbed sample sizes for soils should conform to those given in EM 1110-2-1907. Rock sample sizes can range from 1.875 to 6.0 in. The larger diameter cores are obtained in lieu of the smaller core sizes when rock defects make core recovery and sample quality difficult to obtain. In some cases, the test procedure may dictate the sample size. Rock tests and procedures are presented in the Rock Testing Handbook.

Table 5-2. Factors Causing Undisturbed Samples to be Less Representative of Subsurface Materials

Factor	Effect on Soils	Effect on Rocks
Physical disturbance from sampling and transportation	Effect on shear strength: a. Reduces Q and UC strength. b. Increases R strength. c. Little effect on S strength. d. Decreases cyclic shear resistance. Effect on consolidation test results: a. Reduces P_c. b. Reduces C_c. c. Reduces c_v in vicinity of P_c and at lower stresses. d. Reduces C_a.	Causes breaks in core; may be difficult to obtain intact specimens suitable for testing May seriously affect weakly cemented materials; e.g., for sandstones, may destroy evidence of significant cementation. Foundation may appear to be more fractured than it is May prevent testing of some materials May reduce deformation modulus, E
Changed stress conditions from in situ to ground surface locations	Similar to physical disturbance but less severe	Stress relief may cause physical disturbance similar to that from sampling and transportation. Deformation modulus reduces with decreasing stress field
Contamination of sands from drilling mud	Greatly reduces permeability of undisturbed samples	

Note: Q = Unconsolidated-undrained triaxial test; UC = Unconfined compression test; P_c = Preconsolidation pressure; C_c = Compression index; c_v = Coefficient of consolidation; C_a = Coefficient of secondary compression; R = Consolidated-undrained triaxial test; S = Drained direct shear test.

Section II. Index and Classification Tests

5-3. Soils. Types of index and classification tests that are usually required are listed in table 5-3 together with their reporting requirement. Initially, disturbed samples of soils will be classified according to the USCS. Upon visual verification of the samples, Atterberg limits, mechanical analyses, and moisture content tests will be performed. Table 5-3 also presents two other index tests relating to durability under cyclic weather conditions, and shear strength. The torvane and penetrometer shear tests are simple and relatively inexpensive; however, the tests results can be widely variable and should be used with caution. These shear tests can be helpful as a guide to more comprehensive tests. Slaking tests are valuable when the project is located in moisture sensitive clays and clay shales, and foundation design requirements indicate that the foundation and cut slope areas will be exposed temporarily to wetting and drying conditions.

Table 5-3. Index and Classification Tests for Soils

Test	Remarks
Water content[a]	Required for every sample except clean sands and gravels
Liquid limit and plastic limit[a]	Required for every stratum of cohesive material; always have associated natural water content of material tested (compute liquidity index[b])
Sieve and hydrometer analysis[a]	Generally performed on sands and gravels with occasional tests on cohesive materials. Correlate with Atterberg limit tests (cohesive materials only)
Slaking test	Performed on highly preconsolidated clays and clay shales where deep excavations are to be made or foundations will be near-surface. Wet and dry cycles should be used
Pocket penetrometer and torvane	Performed on cohesive materials, undisturbed samples, and intact chunks of disturbed samples. Regard results with caution; use mainly for consistency classification and as guide for assigning shear tests

[a] See EM 1110-2-1906 for procedures.

[b] Liquidity index = $LI = \frac{w_n - PL}{LL - PL}$.

5-4. Rock. All rock cores will be logged in the field and the log verified by the project geologist or geotechnical engineer, prior to selection of samples for index and classification tests. Types of index and classification tests which are frequently used for rock are listed in table 5-4. Water content, unit weight, total porosity, and unconfined (uniaxial) compression tests will be performed on representative cores from each major lithological unit to characterize the range of properties. The Rock Quality Designation (RQD) values (TM 5-818-1), as developed by Deere (item 10), may be assigned to rock cores (2.125-in. diam) as a guide prior to testing. Additional tests for bulk specific gravity, apparent specific gravity, absorption, elastic constants, pulse velocity, and permeability, as well as a petrographic examination may be dictated by the nature of the samples or by the project requirements. Samples of riprap and aggregate materials will be tested for durability and resistance to abrasion, and the specific gravity of the solids should be determined. Data from laboratory index tests and core quality conditions may be used for rock classification systems such as those developed by Bieniawski (item 6) and Barton, Lien, and Lunde (item 2).

Section III. Engineering Property Tests - Soils

5-5. General. Reference should be made to EM 1110-2-1906 for current soil testing procedures.

a. Shear Strength. Shear strength values are generally based on laboratory tests performed under three conditions of test specimen drainage. Tests corresponding to these drainage conditions are: unconsolidated-undrained Q tests in which the water content is kept constant during the test; consolidated-undrained R tests in which consolidation or swelling is allowed under initial stress conditions, but the water content is kept constant during application of shearing stresses; and consolidated-drained S tests in which full consolidation or swelling is permitted under the initial stress conditions and also for each increment of loading during shear. The appropriate Q, R, and S tests should be selected to reflect the various prototype loading cases and drainage conditions. Normally, strength tests will be made with triaxial compression apparatus except S tests on fine-grained soils, which usually are tested with direct shear apparatus. Where impervious soils contain significant quantities of gravel sizes, S tests should be performed on triaxial compression apparatus using large-diameter specimens.

(1) Q Test. The shear strength resulting from a Q test corresponds to a constant water content condition, which means that a water content change is not permitted either prior to or during shear. The Q test conditions approximate the shear strength for short-term conditions, e.g., the end-of-construction case. In cases where a foundation soil exists that is unsaturated but will become saturated during construction,

Table 5-4. Laboratory Classification and Index Tests for Rock

Test	Test Method	Remarks
Unconfined (uniaxial) compression	RTH[a] 111	Primary index test for strength and deformability of intact rock
Specific gravity of solids	RTH 108	Indirect indication of soundness of rock intended for use as riprap and drainage aggregate
Water content	RTH 106	Indirect indication of porosity of rock or clay content of sedimentary rock
Pulse velocities and elastic constants	RTH 110	Index of compressional wave velocity and ultrasonic elastic constants for correlation with in situ geophysical test results
Rebound number	RTH 105	Index of relative hardness of intact rock cores
Permeability	RTH 114	Intact rock (no joints or major defects)
Petrographic examination	RTH 102	Performed on representative cores of each significant lithologic unit
Specific gravity and absorption	RTH 107	Indirect indication of soundness and deformability
Unit weight and total porosity	RTH 109	Indirect indication of weathering and soundness
Durability	TM 5-818-1, Items 14 and 32	Index of weatherability of rock exposed in excavations and durability of rock for rockfill and riprap
Resistance to abrasion	RTH 115	Los Angeles abrasion test; limited usefulness for evaluating weatherability of riprap

[a] Rock Testing Handbook.

it is advisable to saturate undisturbed specimens prior to axial loading in the Q test.

(2) R Test. The shear strength resulting from an R test is obtained by inducing complete saturation in specimens using back-pressure methods, consolidating these specimens under confining stresses that bracket estimated field conditions, and then shearing the specimens at constant water content. The R test applies to conditions in which impervious or semipervious soils that have been fully consolidated under one set of stresses are subject to a stress change without time for consolidation to take place.

(3) S Test. The shear strength resulting from an S test is obtained by consolidating a sample under an initial confining stress and applying shear stresses slowly enough to permit excess pore water pressures to dissipate under each loading increment. Results of S tests are applicable to free-draining soils in which pore pressures do not develop. In cohesive soils, S tests are used for evaluating the shear strength of long-term conditions, e.g., "normal operating" case.

(4) Selection of Design Shear Strengths. When selecting design shear strengths, the shape of the stress-strain curves for individual soil tests should be considered. Where undisturbed foundation soils and compacted soils do not show a significant drop in shear or deviator stress after peak stresses are reached, the design shear strength can be chosen as the peak shear stress in S direct shear tests, the peak deviator stress, or the deviator stress at 15 percent strain where the shear resistance increases with strain. For each soil layer, design shear strengths should be selected such that two-thirds of the test values exceed the assigned design values.

b. Permeability. To evaluate seepage conditions, reasonable estimates of permeability of pervious soils are required. Field pumping tests (TM 5-818-5) or correlations between a grain-size parameter (such as D_{10}) and the coefficient of permeability, as in figure 3-5 of EM 1110-2-1913, are generally used for coarse-grained materials below the water table. The permeability of compacted cohesive soils for embankments and backfills and for soils modified in place is generally estimated from consolidation tests. Laboratory permeability tests are also being used more frequently for these materials.

c. Consolidation and Swell. The parameters required to perform settlement and rebound analyses are obtained from consolidation tests on highly compressible clays or on compressible soils subjected to high stresses. The sequence and magnitude of test loading should approximate the various prototype loading cases for which settlement and rebound analysis are to be performed. For expansive soils, the standard consolidation test or a modification of this test (item 23) may be used to.

estimate both swell and settlement. Consolidometer swell tests tend to predict minimal levels of heave. Soil suction tests (item 23) can be used to estimate swell. However, this test tends to overestimate heave compared with field observations.

Section IV. Engineering Property Tests - Rock

5-6. General. Table 5-5 lists the laboratory tests frequently performed to determine the engineering properties of rock. These and other rock tests are presented in the Rock Testing Handbook where testing procedures and data reporting are discussed.

Table 5-5. Laboratory Tests for Engineering Properties of Rock

Test	Reference	Remarks
Elastic Moduli from uniaxial compression test	RTH 201[a]	Intact rock cores
Triaxial compressive strength	RTH 202	Deformation and shear strength of core containing inclined joints
Direct shear strength	RTH 203	Strength along planes of weakness (joints) or rock-concrete contact
Creep in compression	RTH 205	Intact rock from foundation where time-dependent compression is an important factor in design
Thermal diffusivity	RTH 207	Intact rock subjected to elevated temperatures such as adjacent to mass concrete where heat conductance is a factor

[a] Rock Testing Handbook.

a. Unconfined Uniaxial Compression Test. The unconfined uniaxial compression test is performed primarily to obtain the elastic modulus and unconfined compressive strength of a rock sample. Poisson's ratio can be determined if longitudinal and lateral strain measurements are made on the sample during the test. The value of Poisson's ratio is required for describing the deformation characteristics of a rock mass. Occasionally design requirements dictate the need for testing of samples at different orientations to describe three-dimensional anisotropy.

b. Direct and Triaxial Shear Tests. Laboratory triaxial and direct shear tests on intact rock cores and intact rock cores containing recognizable thin, weak planes are performed to determine approximate values of cohesion, c (shear strength intercept), and angles of internal shearing resistance, ϕ , of a rock type. Direct shear tests on discontinuous (natural joints and smooth presawn surfaces) rock cores are performed to determine the angle of joint friction for the discontinuity considered. In addition, the bonding strength of a rock-concrete contact can be determined by this test. Values of cohesion and angles of internal friction are used to determine strength parameters of foundation rock. These values are the principle parameters in the analytical procedures to define the factor of safety. They are appropriate in analyses of the stability of rock slopes, and structures subjected to nonvertical external loading. The application of these values is discussed in detail in Corps of Engineers guidance on gravity dam design, and in items 33 and 51.

(1) Direct Shear Test. Detailed procedures for making the laboratory direct shear test are presented in the Rock Testing Handbook (RTH 203). The test is performed on core samples ranging from 2 to 6 inches in diameter. The samples are trimmed to fit into a shear box or machine, and oriented so that the normally applied force is perpendicular to the feature being tested. Results of tests on intact samples will give upper bound strength values while tests on smooth surfaces give lower bound values. Repetition of the shearing process on a sample, or continuing displacement to a point where shear strength becomes constant, can ultimately establish the residual shear strength value. Where natural joints control the rock mass shear strength, tests should be performed to determine the friction angle of the joint asperities as well as the smooth joint plane. The direct shear test is not suited to the development of exact stress-strain relationships because of the nonuniform distribution of shearing stresses and displacements within the test specimen. For the test results to have valid application, test conditions must be as close as possible to actual field conditions.

(2) Triaxial Shear Test. The triaxial shear test can be made on intact, cylindrical rock samples. The test provides the data for determination of rock strength in an undrained state under three-dimensional loading. Data from the test can provide, by calculation, the strength and elastic properties of the rock samples at various confining pressures, the angle of shearing resistance, the cohesion intercept, and the deformation modulus. Strength values are in terms of total stress as pore water pressure is not measured, and corrections should be made accordingly. A variation of this test using multistage triaxial loading, RTH 204, is sometimes used for evaluating the strength of joints, seams, and bedding planes at various confining pressures.

Section V. Engineering Property Tests - Shales and Moisture-Sensitive Rocks

5-7. General. Most of the moisture-sensitive rock forms are sedimentary in origin or their metamorphic equivalents. These rock types range from indurated clays to compaction shales, poorly to moderately cemented sandstones, and the earthy rock types such as marl. In some cases, the weathered product of a rock type may be the sensitive material in the overall rock mass and can be the result of chemical weathering (saprolite) or rock movement (fault gauge, mylonite). As these rock forms have soillike characteristics, the index properties of these materials should be determined prior to more comprehensive testing. The results of the index testing, i.e., Atterberg limits, moisture content, etc., will usually indicate the engineering sensitivity of the rock forms, and should be used as a guide to further testing. Special procedures may be necessary for index testing and reference to EM 1110-2-1906 is recommended.

a. Direct and Triaxial Shear Tests. Most direct and triaxial shear tests conducted on hard, brittle rock samples are of the undrained type. For these particular types of materials, pore pressures do not play a dominant role, and strength values are in terms of total stress. However, as softer rock types are encountered, with correspondingly higher absorption values (e.g., greater than 5 percent), the role of pore pressure buildup during the rock shearing process begins to become more important. The same condition is true for many clay shales and other similar weak and weathered rock materials. For moisture-sensitive rocks, soil property test procedures should be used when possible. Critical pore pressures that may substantially reduce the net rock strength can then be monitored throughout the entire testing cycle.

b. Test Data Interpretation. Laboratory test data on shales and moisture-sensitive rocks should be interpreted with caution. The laboratory undrained strength of intact specimens is rarely representative of in-place field shear strengths. Frequently, shales, clay shales, and highly overconsolidated clays are reduced to their residual shear strength with minor displacements. The geotechnical explorations, laboratory testing, and review of field experiences must establish whether residual or higher shear strengths are appropriate for design purposes. Results of laboratory tests should be confirmed by analysis of the field behavior of the material from prior construction experience in the area, analysis of existing slopes or structures, and correlation with similar geologic formations at sites where the field performance is known. For a general engineering evaluation of the behavioral characteristics of shales, see table 3-7 of TM 5-818-1 and items 45 and 46; for physical properties of various shale formations, see table 3-8 of TM 5-818-1.

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APPENDIX B
GEOLOGIC MAPPING PROCEDURES
OPEN EXCAVATIONS

B-1. Purpose of Excavation Mapping. The primary purpose of the excavation map and/or foundation geologic map is to provide a permanent record of encountered conditions. This permanent record will assist in making the most equitable contract adjustment for construction changes, provide otherwise unattainable information for use in diagnosing postconstruction problems and in planning remedial action, and allow for a better interpretation of postconstruction foundation instrumentation data. An important prelude to performing the geologic mapping of the final foundation and/or excavation is monitoring conditions during excavation. Monitoring conditions during excavation provides the basis for discovering, at the earliest possible moment, those adverse conditions (differing from original predictions) that may cause expensive design and construction delays. A plan for monitoring also provides a basis for installing appropriate instrumentation and assists in the interpretation of foundation instrumentation data as the excavation proceeds.

B-2. Possible Adverse Conditions.

a. Adverse conditions can affect the stability of excavated slopes during construction, stability of permanent slopes, foundation settlement, foundation bearing capacity, sliding stability of structures, and planned water control measures such as grouting and drainage requirements. Such conditions can occur in both soil and rock. The presence of water can affect conditions in both soil and rock. Features of engineering significance in both soil and rock frequently occur in geometrically predictable patterns. The prediction of geometry is enhanced by knowledge of the local geologic history.

b. Adverse conditions that can occur in soils include soft compressible zones of clay or organic materials; lateral changes due to variations in depositional environment; changes in the relative density of granular materials; swelling or slaking in hard, fissured clays; and changes in permeability.

c. Adverse conditions that can occur in rocks include weathering, soft interbeds in sedimentary and volcanic rocks, lateral changes, presence of materials susceptible to volume change (e.g., swelling clay shales, sulfide-rich shales, gypsum, and anhydrite), adversely oriented fractures (e.g., joints, bedding planes, schistosity planes, and shear planes), and fault, joints, or shear planes filled with soft materials.

d. Adverse conditions that can occur because of the presence of water include unexpectedly high cleft or pore pressures which reduce effective stress, swelling materials, slaking, piping, sand runs, and uplift pressures on partially completed structures. It should be noted that most water-induced problems stem from unanticipated changes in the water regime.

B-3. Monitoring and Mapping Procedures.

a. The difference between excavation monitoring and record mapping is small; both involve the observation and reporting of natural conditions. The need for monitoring the condition of slopes during construction include safety during construction and the prediction of conditions at grade. Potential problem areas can be detected and avoided or corrective treatment can be started before the problem becomes severe. Mapping is performed to compile a permanent record of foundation conditions.

b. Depending on the speed of excavation, monitoring should be performed on a daily, twice weekly, or weekly basis. Table B-1 is an excavation monitoring checklist, which, if followed should insure adequate coverage. Geologic sections can be constructed to assist in predicting the locations of features at grade. While many geologic features are arcuate or sinuous, many are planar. The location of a planar feature at grade can be found by graphic projection or by calculation as shown on figure B-1.

c. Excavation and foundation mapping are usually performed on an intermittent and noninterference basis. If advantage is not taken of every mapping opportunity, the rock surface may be covered before another opportunity occurs or the contractor may be subjected to undue delay. Further, systematic mapping makes for better monitoring. The thoroughness of mapping, type of mapping procedure, and sequence in which it is accomplished are functions of the purpose for which the mapping is required and of the construction schedule.

d. A number of items should be done to prepare for mapping before the excavation is started.

(1) The geologist with mapping responsibility should make an interpretation, or confirm the existing interpretation, of the geologic conditions (a geologic model). He should decide on the mechanics of mapping and prepare field base map sheets. The map scale is partially dependent on the amount of detail that will be mappable. If the excavation will be in hard, fractured rock, a field scale of 1 in. = 5 ft and a final compiled map scale of 1 in. = 10 ft would be suitable. If the excavated material is a soil, a soft lightly fractured sedimentary rock, or a glacial till, field and compiled scales of 1 in. = 10 ft

Table B-1. Suggested Geologic Excavation Monitoring Checklist

Project ______________________________

Excavation For ______________________________ Structure

Period: ________ to ________

1. Excavation Progress:
   a. Type Excavation: ________ (common or rock) ________
   b. Location: Sta________to________Offset________
2. Rock or soil type: ______________________________
3. Rock or soil conditions: ______ (hardness, stiffness, weathering, fracturing, sloughing, etc.) ______
4. Water inflow, locations and gpm: ______________________________
5. Significant features or defects: (those which may cause problems (and/or may extend to grade) ______
6. Slope protection: ______ (protection or reinforcement, location, type thickness, etc.) ______
7. Blasting conditions: ______ (presplitting locations and successes, production blasting, powder factor, hole spacing, delay patterns, deviations from approved rounds, fragment size, overbreak, etc.) ______
8. Ripping conditions: ______ (single or multitooth, drawbar horsepower, easy or hard, disturbance below grade or slopes) ______

(Continued)

Table B-1 (Concluded)

9. Additional remarks: ______ (unusual incidents, accidents, explorations, etc.) ______

______

______

10. Mapping progress:

    a. Location ______

    b. Adequacy of coverage ______ (rock surface clean?, percent obscured by slope protection?, etc.) ______

    ______

    c. Photos taken: ______ (where, or what) ______

    ______

    ______

    ______

11. Instrumentation installed:

    a. Location ______

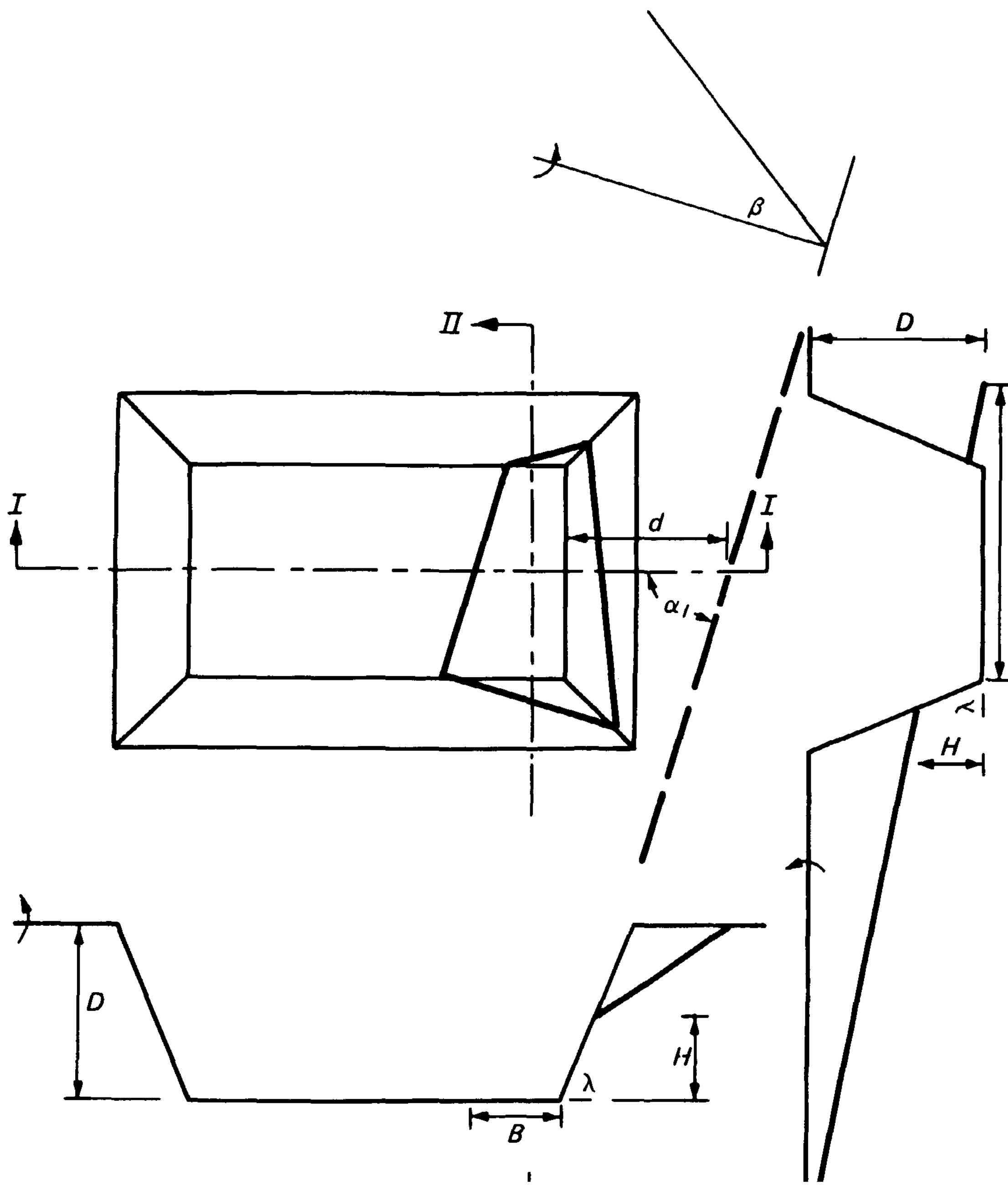
    b. Type and amount ______

    ______

12. Instrumentation read:

    a. Location ______

    b. Type ______



$$B = \frac{D}{\tan\beta \sin\alpha} - d \text{ and}$$

$$H = \frac{D - d\,(\tan\beta \sin\alpha)}{1 - \cot\lambda \tan\beta \sin\lambda} \text{ or}$$

$$B = H\left(\frac{1}{\tan\beta \sin\alpha} - \frac{1}{\tan\alpha}\right) \text{ where:}$$

α = acute angle between strike of planar feature and section
β = true dip of planar feature
λ = acute angle of excavation slope
B = distance, in section, from toe of excavation slope to outcrop at excavation grade
d = distance, at section, from toe of excavation slope to surface outcrop of feature
D = depth of excavation
H = height in section of feature outcrop above grade

and 1 in. = 50 ft could be suitable. The field base maps should have reference lines for location purposes. In structure foundation areas, the structure outline will be enclosed by concrete forms that are easily locatable, making handy reference lines. The location of features inside reference lines can be facilitated by use of cloth tape grids.

(2) Decide at what intervals to map as the excavation progresses. Mapping intervals will be affected by a number of factors including the rate of excavation, lift thicknesses, and the need for temporary slope protection. In most cases, the mapping should be done in the plane of the slopes; projection to other planes can be made after the mapping is completed. An exception occurs when the mapping is done with a plane table. In this case, a horizontal reference plane is required. Camera positions should be selected for sequential photographs during excavation. Reference lines for mapping can be provided by stretching tapes from the top to bottom of the slope at 10- to 20-ft intervals. Final excavation topographic maps should be made that can be used as a base for the geologic map.

(3) Determine whether the side slopes will be too steep for unassisted access. Temporary soil slopes usually range from 1V on 3H to 1V on 1H. Temporary rock slopes usually range from 1V on 1H to vertical. It is not possible to walk slopes steeper than 1V on 1-1/2H unless they are very irregular. Thus, safety lines will be needed on most rock slopes and on some soil slopes.

(4) When the slopes are nearly vertical, consideration can be given to mapping on large-scale photographs. However, there must be time to produce the photographs for use as a map base.

e. It is desirable to have a contract provision for interim rock surface cleanup. The final foundation cleanup item will suffice for mapping purposes at final grade. However, the need may arise for detailed examination of particular areas during excavation. Excavation slopes may need sealing or other interim protection against weathering.

f. During mapping, complete descriptions of all geologic features should be made (e.g., rock types, bedding, fracturing, joints, shear zones, etc.). All features, geologic and otherwise (including ledges and breaks in slope) should be located and drawn on the base map. Table B-2 provides descriptive criteria for use during mapping. Insofar as possible, the information on table B-2 is consistent with information provided in EM 1110-1-1806.

Table B-2. Descriptive Criteria, Excavation Mapping

1. Rock Type.

a. Rock Name (Generic).

b. Hardness.

(1) Very soft: can be deformed by hand.

(2) Soft: can be scratched with a fingernail.

(3) Moderately hard: can be scratched easily with a knife.

(4) Hard: can be scratched with difficulty with a knife.

(5) Very hard: cannot be scratched with a knife.

c. Degree of Weathering.

(1) Unweathered: no evidence of any mechanical or chemical alteration.

(2) Slightly weathered: slight discoloration on surface, slight alteration along discontinuities, less than 10 percent of the rock volume altered, and strength substantially unaffected.

(3) Moderately weathered: discoloring evident, surface pitted and altered with alteration penetrating well below rock surfaces, weathering "halos" evident; 10 to 50 percent of the rock altered, and strength noticeably less than fresh rock.

(4) Highly weathered: entire mass discolored, alteration pervading nearly all of the rock with some pockets of slightly weathered rock noticeable, some minerals leached away, and only a fraction of original strength retained (with wet strength usually lower than dry strength).

(5) Decomposed: rock reduced to a soil with relict rock texture (saprolite), and generally molded and crumbled by hand.

d. Lithology, Macro Description of Mineral Components. Use standard adjectives such as shaly, sandy, silty, and calcareous. Note inclusions, concretions, nodules, etc.

(Continued)

Table B-2 (Continued)

e. Texture and Grain Size.

(1) Sedimentary rocks:

Texture	Grain Diameter	Particle Name	Rock Name
*	80 mm	cobble	conglomerate
*	5 - 80 mm	gravel	
Coarse grained	2 - 5 mm		
Medium grained	0.4 - 2 mm	sand	sandstone
Fine grained	0.1 - 0.4 mm		
Very fine grained	0.1 mm	clay, silt	shale, claystone, siltstone

* Use clay-sand texture to describe conglomerate matrix.

(2) Igneous and metamorphic rocks:

Texture	Grain Diameter
Coarse grained	5 mm
Medium grained	1 - 5 mm
Fine grained	0.1 - 1 mm
Aphanite	0.1 mm

(3) Textural adjectives: Use simple standard textural adjectives such as porphyritic, vesicular, pegmatitic, granular, and grains well developed, but not sophisticated terms such as holohyaline, hypidiomorphic granular, crystalloblastic, and cataclastic.

2. Rock Structure.

a. Bedding.

(1) Massive: 3 ft thick.

(2) Thick bedded: beds from 1 - 3 ft thick.

(3) Medium bedded: beds from 0.3 ft - 1 ft thick.

(4) Thin bedded: beds less than 0.3 ft thick.

(Continued)

Table B-2 (Continued)

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b. Degree of Fracturing (jointing).

(1) Unfractured: fracture spacing 6 ft.

(2) Slightly fractured: fracture spacing 3-6 ft.

(3) Moderately fractured: fracture spacing 1-3 ft.

(4) Highly fractured: fracture spacing 0.3-1 ft.

(5) Intensely fractured: fracture spacing 0.3 ft.

c. Shape of Rock Blocks.

(1) Blocky: nearly equidimensional.

(2) Elongated: rodlike.

(3) Tabular: flat or bladed.

3. Discontinuities.

a. Joints.

(1) Type: bedding, cleavage, foliation, schistosity, and extension.

(2) Separations: open or closed; how far open.

(3) Character of surface: smooth or rough; if rough, how much relief; average asperity angle.

(4) Weathering or clay products between surfaces.

b. Faults and Shear Zones.

(1) Single plane or zone: how thick?

(2) Character of sheared materials in zone.

(3) Direction of movement, and slickensides.

(4) Clay fillings.

(Continued)

Table B-2 (Concluded)

c. Solution Cavities and Voids.

(1) Size.

(2) Shape: planar, irregular, etc.

(3) Orientation: (if applicable) developed along joints, bedding planes, at intersections of joints and bedding planes, etc.

(4) Filling: percentage of void volume and type and of filling material (e.g., sand, silt, clay, etc.).

g. To the maximum extent possible, USGS map symbols or variations of these symbols should be used during mapping. In most cases, the geologist should represent geologic features by showing the trace of the feature on the map. The trace will allow a reasonably accurate location of each significant feature.

h. Frequently, foundation maps and sections are prepared with rock type symbols sketched or zip-a-toned over the entire area of the particular rock type. However, if all the recognizable distinct geologic features are also located on the drawing, it will be cluttered and hard to read. Thus, the primary purpose of the foundation record will be obscured. Each mark on the foundation map should have physical significance.

i. Records should be made of foundation treatment, such as grout hole locations, dental work, pneumatic concrete, rock-bolt locations, and wire mesh. Portrayal of such treatment can be included on the geologic map. However, if the resulting map is too cluttered, either the treatment should be portrayed on a separate sheet or transparent overlays, or the scale of the mapping should be enlarged.

j. The importance of adequate photography of the excavation process and the final slope and foundation conditions cannot be overemphasized. Complete photographic coverage is as important as the foundation maps. Both are required for an accurate and complete record of encountered conditions.

k. The photographic coverage should include unobstructured, medium-scale photographs of the entire foundation and closeup views of significant geologic features; a photograph through a mat of reinforcing steel is useless. All photographs should be annotated by the geologist and clearly sited on a photograph of the location map.

B-4. <u>Explanation of Figures B-2 through B-8.</u>

a. Figures B-2 through B-8 are examples of foundation maps.

b. Figures B-2 and B-3 depict foundation maps for concrete structures in metavolcanic and igneous rocks where the geologists have attempted to portray the entire trace of all significant geologic features. Figure B-4 is a tunnel map in the same kinds of materials as portrayed in figure B-3 and also provides a legend for figure B-3. Figure B-5 is a smaller scale map of an excavation in metavolcanic rocks and also includes the foundation mapped in detail in figure B-3.

c. Figure B-6 is a foundation map for the impervious core of an earth dam founded on metavolcanic and igneous rocks. The geologist has mapped the full traces of shears, contacts, and igneous dikes but has shown joints and lineations by symbols only.

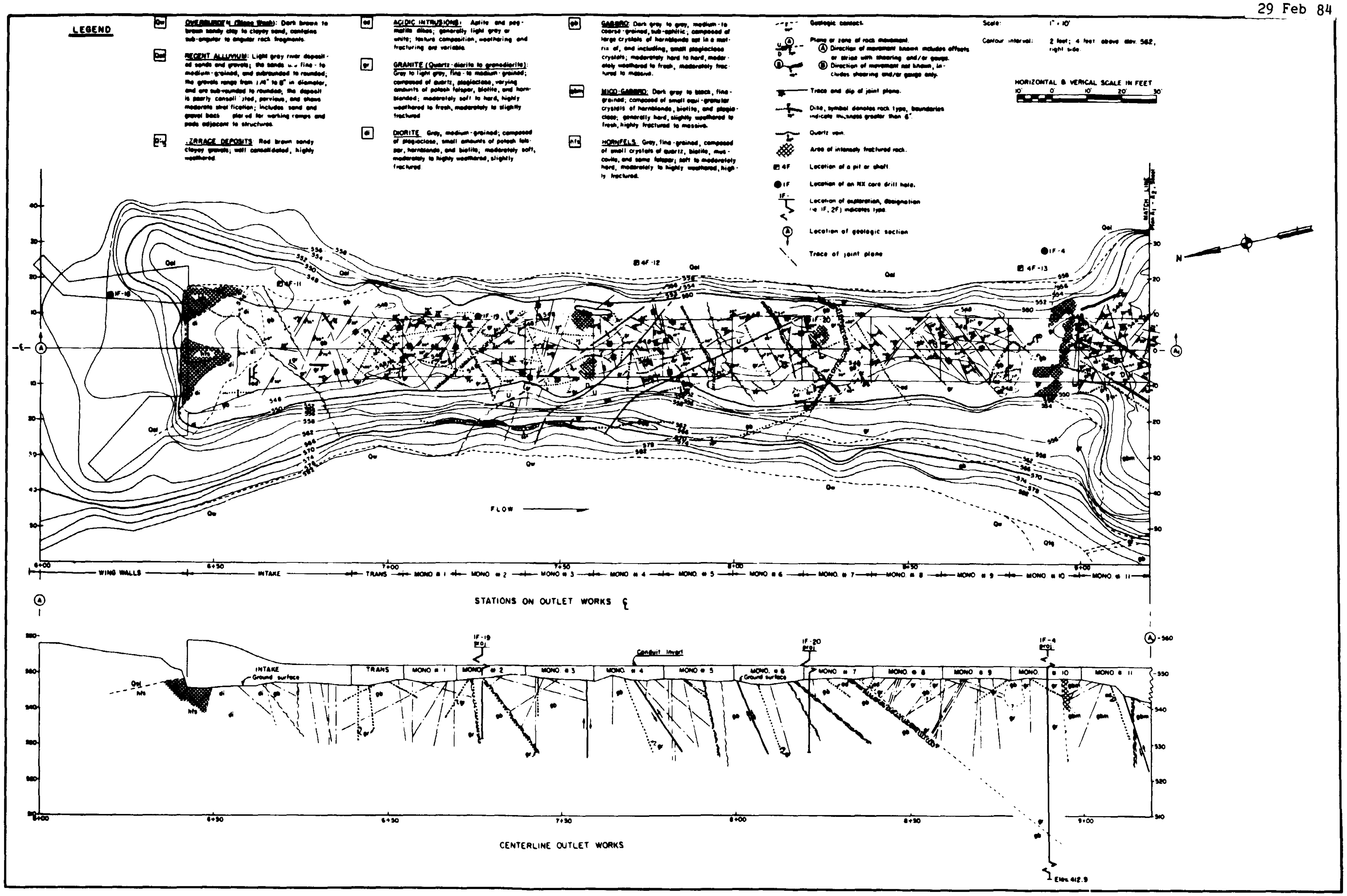


Figure B-2. Foundation map for concrete structure on metavolcanic and igneous rocks

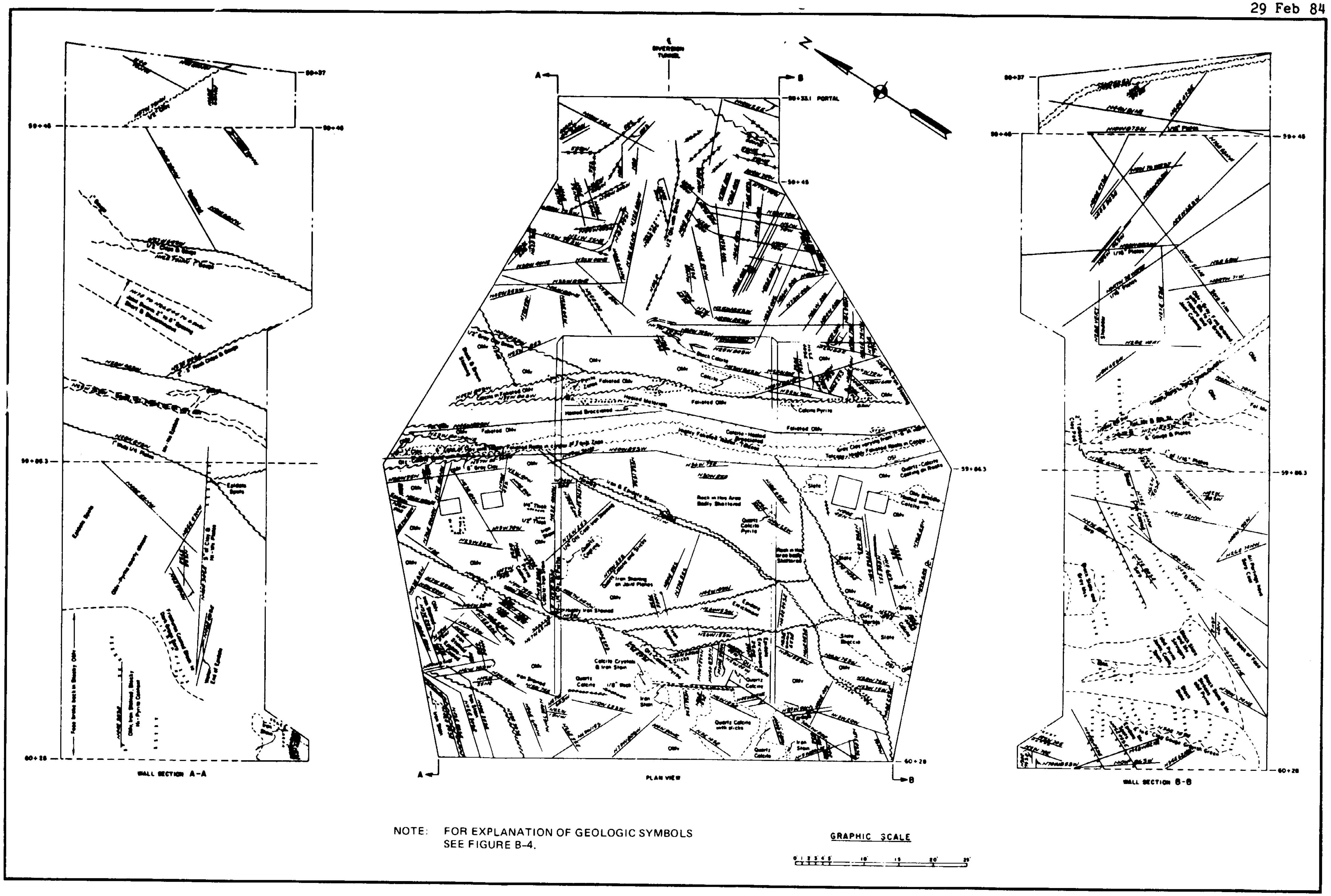


Figure B-3. Foundation map for concrete structure on metamorphic rocks

EXPLANATION OF SYMBOLS

Mv	META-VOLCANICS. Grayish green, moderately hard to hard, fine-grained to fragmental, contains variable amounts of dark green pyroxene grains, calcite, quartz, and epidote.
Mss	META-SANDSTONE. Black to dark gray, moderately hard to hard, fine-grained, massive variable amounts of meta-volcanic fragments and black slate.
S1	SLATE. Black, moderately hard, fine-grained, moderately fissile, contains variable amounts of calcite and pyrite.
S1br	SLATE BRECCIA. Black with gray streaks, moderately hard, contains layers and fragments of meta-sandstone and meta-volcanic rock types in a slaty groundmass, is crudely foliated.

OLDER METAMORPHICS

OMv	META-VOLCANICS. Light gray to gray, moderately soft to moderately hard, fine-grained, crudely to moderately foliated, contains black slate streaks.
TOMv	META-VOLCANICS. Partially replaced by soapstone or talc.
OS1	SLATE. Black, moderately soft to moderately hard, fine-grained, moderately fissile to fissile.
OTS1	SLATE. Partially replaced by soapstone or talc.
OS1br	SLATE BRECCIA. Dark gray to black, moderately hard, contains angular fragments of meta-sandstone and meta-volcanics, moderately fissile.
OMvc	META-VOLCANICS CONGLOMERATE. Greenish gray, moderately hard to hard, fine-grained meta-volcanic groundmass enclosing rounded fragments of meta-volcanics, meta-sandstone, chert and marble and plates of slate.
OMss	META-SANDSTONE. Gray, fine- to medium-grained and moderately hard.
Mar	MARBLE. Gray, moderately hard, finely crystalline.
Serp	SERPENTINE. Dark green to black, soft to moderately hard, has a waxy lustre; partially to completely replaces surrounding rock types.
Md	MICRO-DIORITE DIKES. Gray, moderately hard, fine- to medium-grained; contains numerous transverse quartz-calcite seams and are from two to eighteen inches wide.
xxx	QUARTZ-CALCITE. Veins.

cont.	contorted
fol.	foliated
stks.	streaks
crud.	crudely
○	grout hole
●	IF-1 core hole
$\frac{N60W}{50S}$	strike and dip of joint
$\frac{N10W}{60E}$	strike and dip of cleavage
— — —	geologic contact
⁄\/\/	fault
⁀⁀⁀	shear

NOTES

1. Hard - difficult to scratch with a knife.
2. Moderately hard - can be scratched easily with a knife.
3. Moderately soft - can be carved with a knife.
4. Soft - can be gauged with a copper penny.
5. Very soft - can be gauged with a finger nail.
6. See text for detailed rock description.

Figure B-4. Explanation of symbols

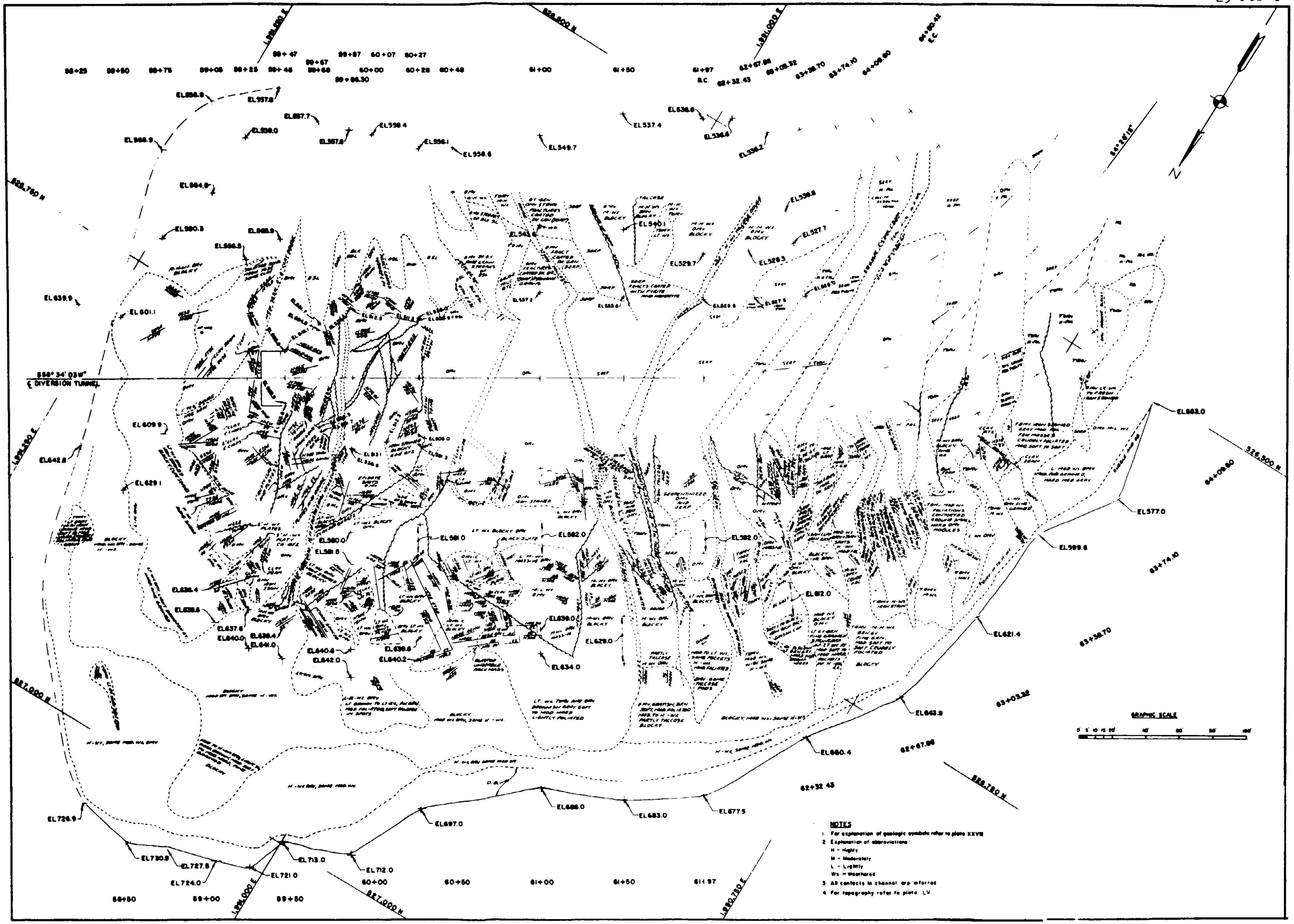


Figure B-5. Excavation map including area covered by Figure B-3

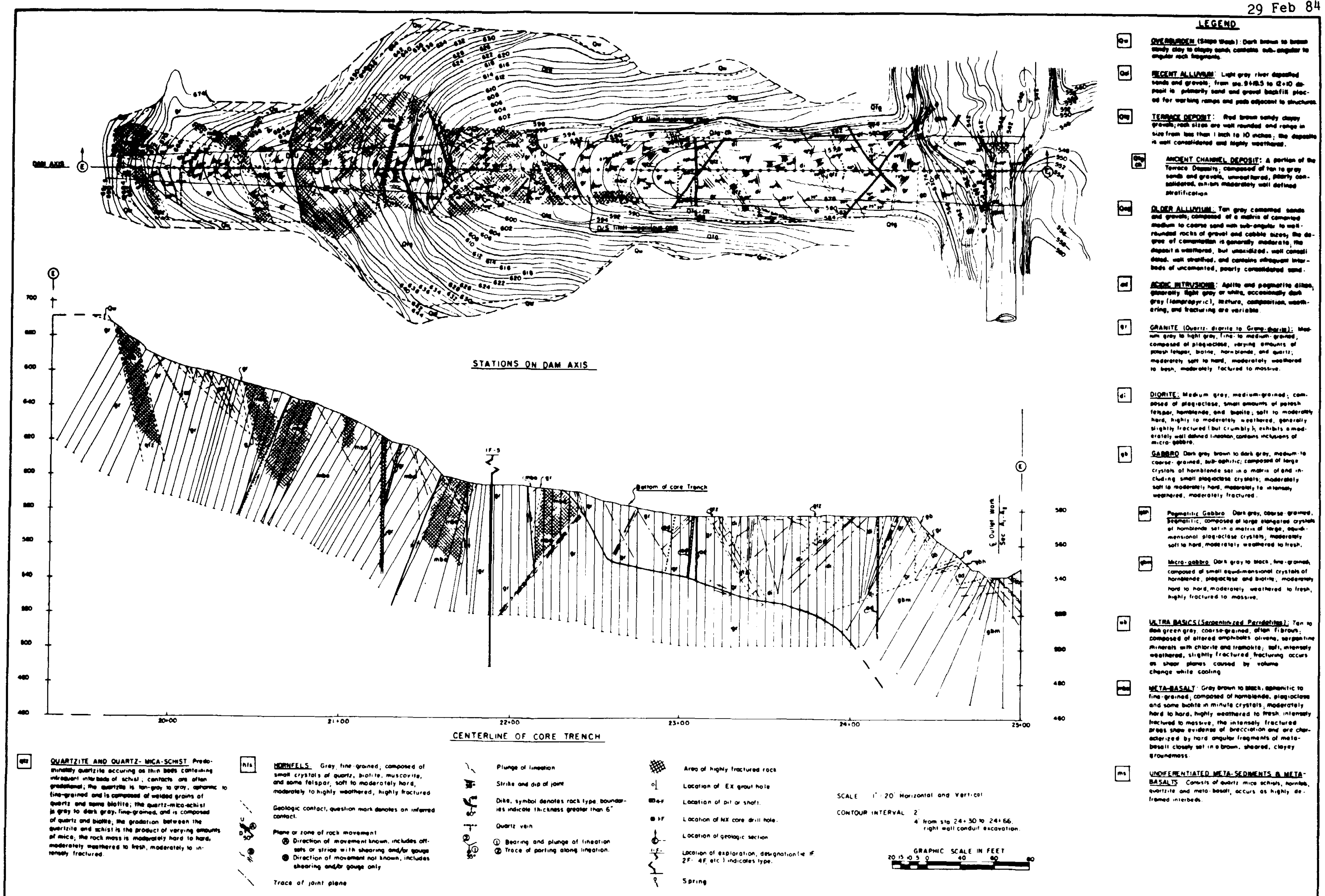


Figure B-6. Foundation map for earth dam impervious core on metavolcanic and igneous rocks

d. Figure B-7 depicts a detailed foundation map for a concrete structure founded in sedimentary rocks. The geologist has located the full trace of all significant geologic features.

e. Figure B-8 depicts the foundation for a cutoff trench in sedimentary rocks.

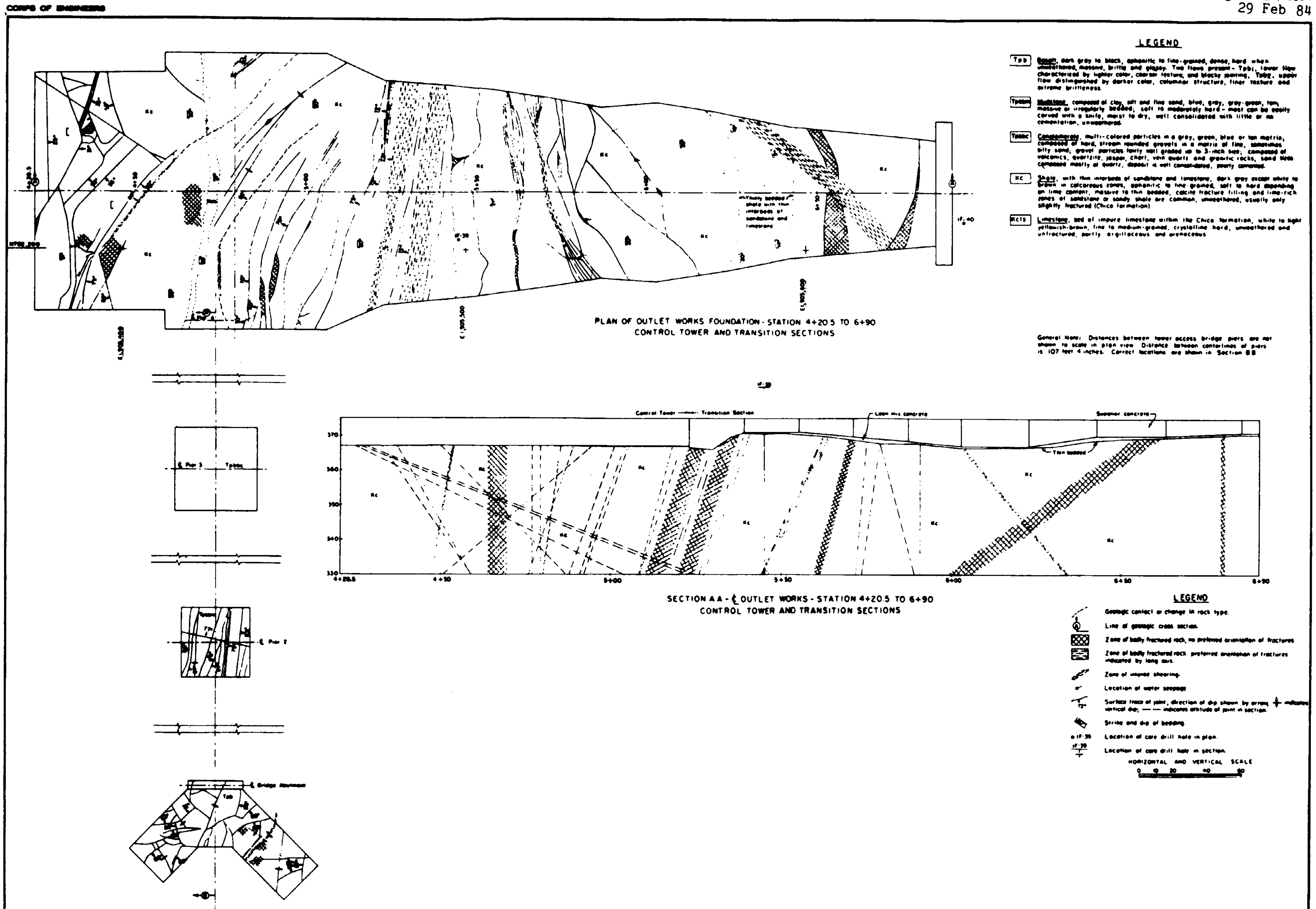


Figure B-7. Foundation map for concrete structure on sedimentary rocks

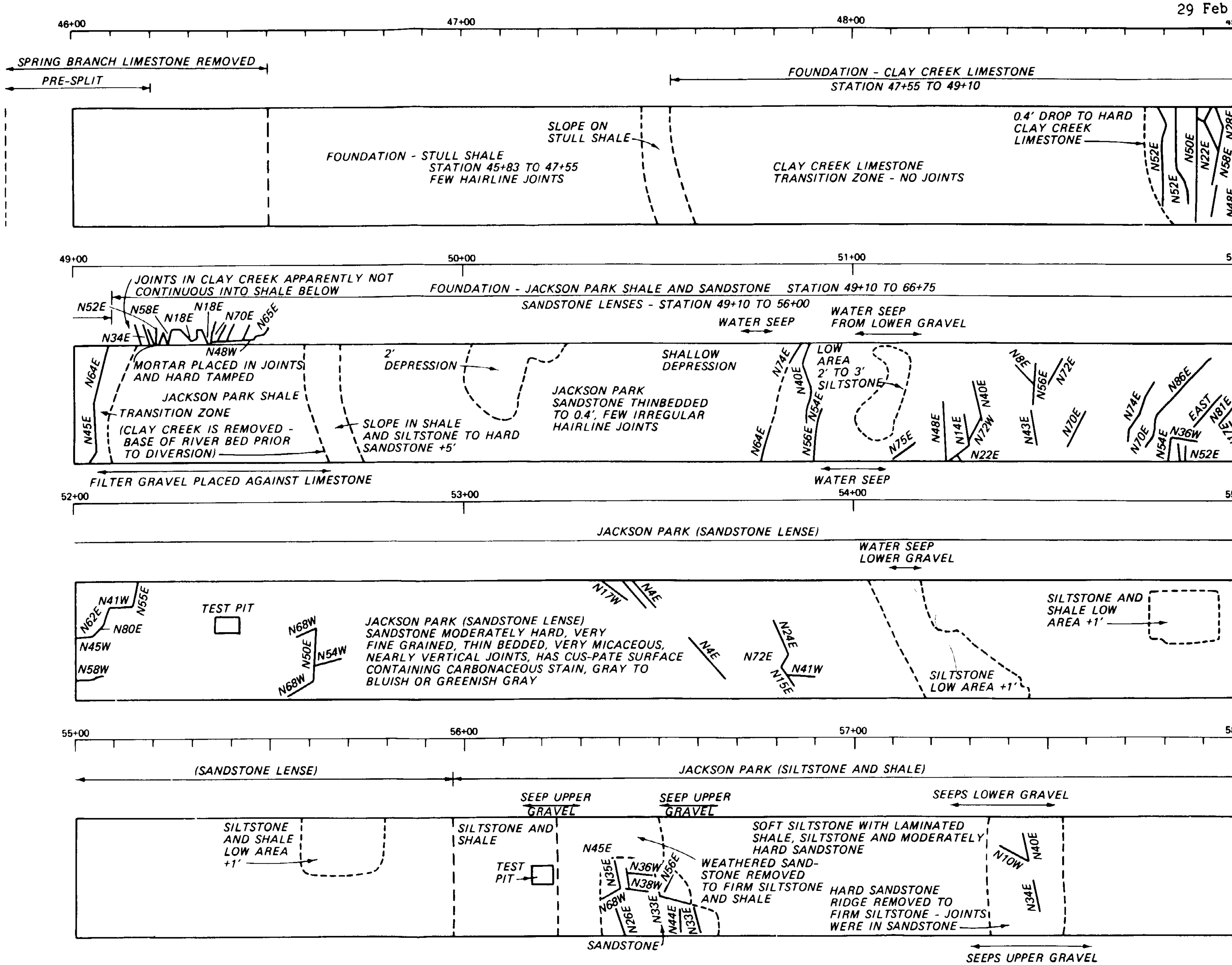


Figure B-8. Foundation map for earth dam impervious core on sedimentary rocks

APPENDIX C
GEOLOGIC MAPPING OF TUNNELS AND SHAFTS

C-1. Background. A method to log all geologic features exposed by underground excavations has been developed by U. S. Army Engineer District, Omaha, geologists where all necessary data of a specific geologic discontinuity can be recorded at a single point; thus the system may be used in tunnels of almost any configuration and inclination. This method is called peripheral geologic mapping. It allows logging of all geologic defects regardless of their position on the tunnel walls. Furthermore, this method usually will keep pace with modern continuous mining techniques and will provide immediately useful data without projecting to plan or profile. Prior to development of this method, the accepted method was to project geologic features to a plan placed tangent to a point on the tunnel circumference. Ordinarily such tangent points were at springline, wasteline level, or crown. In many instances, geologic features not passing through these points were not logged. Further, some systems were useful for logging planar discontinuities only, such as joints, faults, and bedding planes, as exposed in straight, nearly horizontal tunnels of circular cross section. Peripheral geologic mapping uses a developed plan by "unrolling the circumference" to form a plan of the entire wall surface. A log of the exposed geology is plotted on this plan as mining progresses. Mapping on a developed layout of a cylindrical surface is similar to the method used to log the interior of a calyx hole. Actually, a circular tunnel might be visualized as a large horizontal or nearly horizontal drill hole.

C-2. Applications. Peripheral geologic mapping may be used to log large-diameter power tunnels and surge tank risers (both straight and wye-shaped), vertical shafts, horseshoe-shaped drifts and chambers, and various odd-shaped openings on both civil and military projects. It can be used in stratified, soft, sedimentary rocks and hard, granitic rock masses. The method has proved to be simple enough mechanically that subprofessionals can be trained to perform round-the-clock mapping under the general supervision of a professional geologist--a necessity when several parallel tunnels are driven simultaneously.

C-3. Procedure.

a. Advance planning is of paramount importance. The developed layouts on which mapping will be done should be prepared well in advance. Usually this step in the procedure can be accomplished by using the contract plans. A thorough surface and subsurface study of the geology of the immediate area is recommended. This study enables the mapper to recognize which geologic features are important and also identify them on the excavation walls.

b. The map is usually laid out to a scale of 1 in. equals 10 ft. In some instances where closely-spaced geologic discontinuities are anticipated, a scale of 1 in. equals 5 ft should be considered. To prepare a mapping plan, draw the crown center line of the tunnel in the center of the plan. Place the center line of the invert at both the right- and left-hand edges of the developed layout. The right and left springlines of a circular tunnel will be midway between the center line and edges of the plans (fig. C-1). Distances down tunnel may be laid out on tunnel stationing. Separate developed plan tracings are usually made for 100-ft lengths of tunnel. For long reaches of equal diameter tunnel, a master tracing may be repeatedly printed on a continuous length of paper to cover the entire tunnel length. (For continuous uninterrupted printing use three master tracings.) This long sheet of paper may be rolled up and carried in the field in the form of a scroll.

c. Intermediate control points should be added wherever possible to more precisely locate points along geologic discontinuities. On figure C-2, which is a mapping sheet used at Fort Randall Dam, South Dakota, the horizontal distances from the center line and vertical distances from springline were computed and drawn on the developed plan to form a grid. When plotting a point, the mapper measures these two distances (horizontal distance from center line and vertical distance above or below springline) and plots the point at the proper tunnel stationing. To eliminate long measurements in large-diameter tunnels, distances were actually measured from fixed known points on the tunnel support ring beams (splices, bolt holes, and spreader bars). Later at Oahe Dam, South Dakota, horizontal and vertical distances of fixed features on the ring beam supports were drawn on the mapping sheets as lines so that points on geologic features could be plotted from the nearest ring beam reference point. On figure C-3, which is a mapped portion of Oahe Dam power tunnel No. 2, a developed ring beam is shown at the top of the page, vertical distances from springline of identifiable fixed points on the ring beam are shown along the top of the mapping section, and horizontal distances from center line of these same points are shown along the bottom of the mapping section. The ring beam number and its tunnel station is shown along the right-hand edge. Excellent mapping control was thus provided on this project. In excavations not requiring close checks on alinement, control points may be almost nonexistent. Then the mapper must provide more of his own control. He may have to stretch a tape along the tunnel from the nearest spad, then mark stationing at 5- or 10-ft intervals along the walls, and use an assumed elevation at his reference point. Obviously, the resultant geologic log will not be as accurate, but the relative position of discontinuities should remain constant from tunnel wall to geologic log.

d. The conventional method of measuring the strike, or orientation of a joint, shear, or fault, by magnetic needle (Brunton) compass

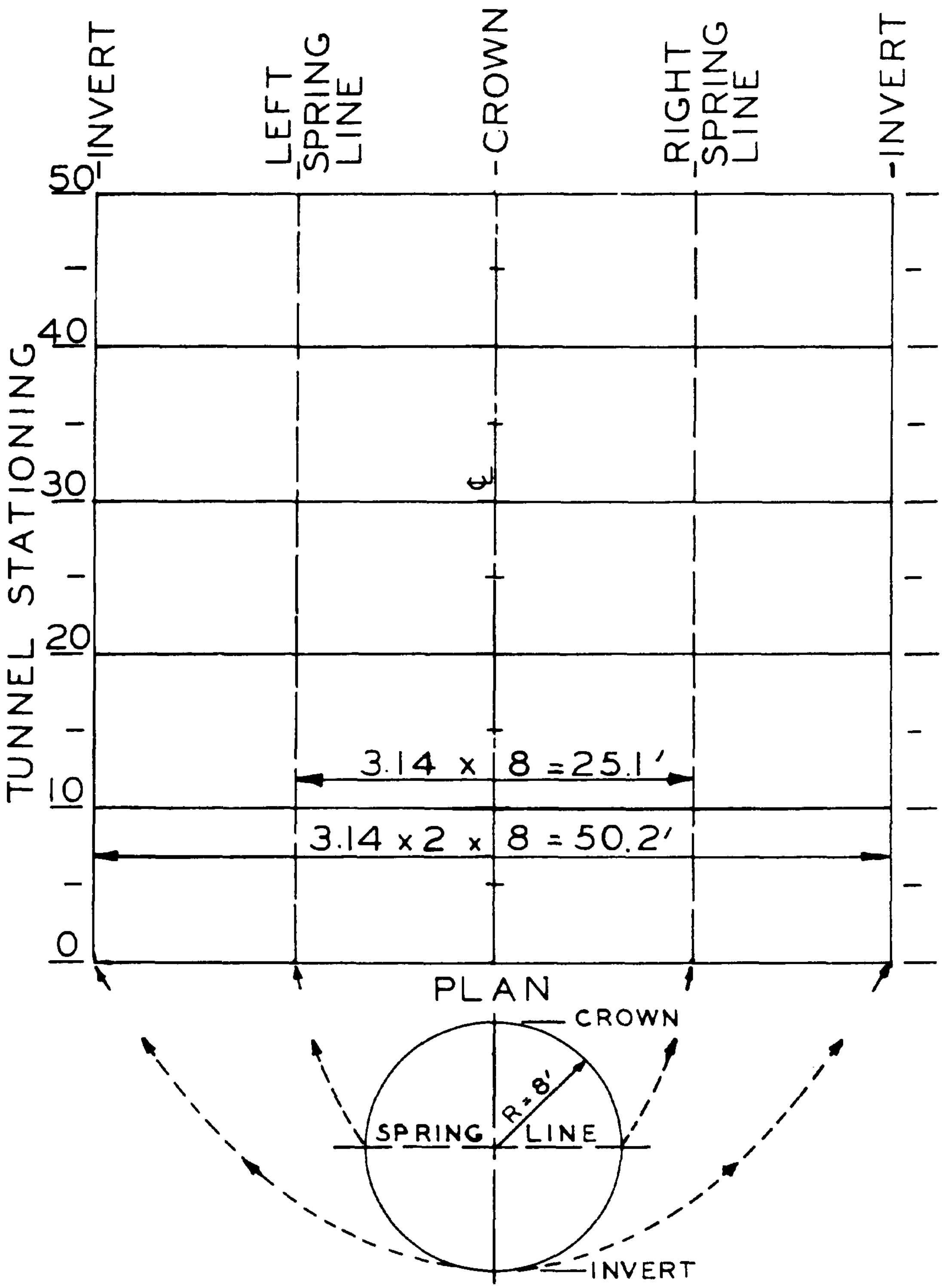
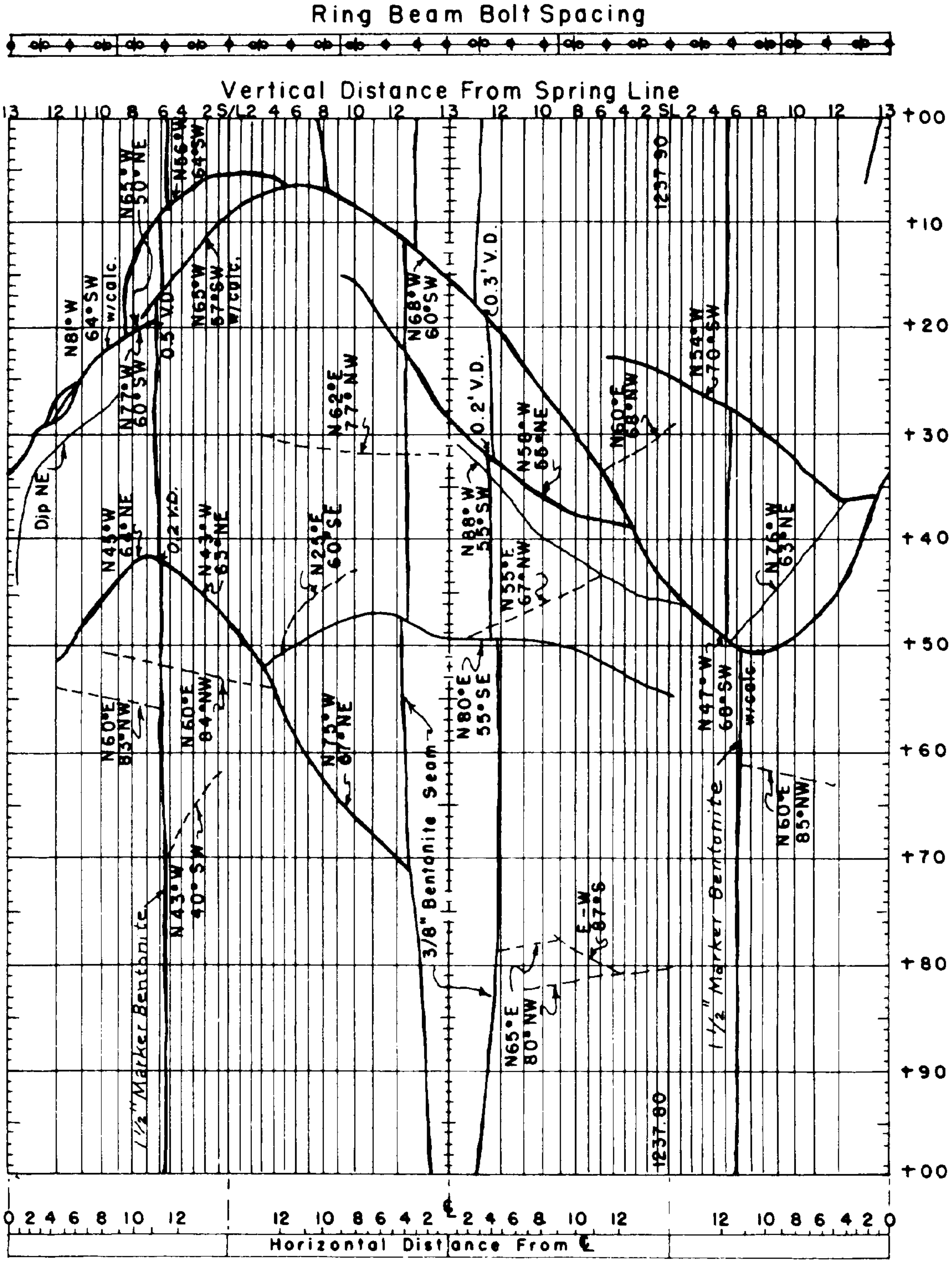
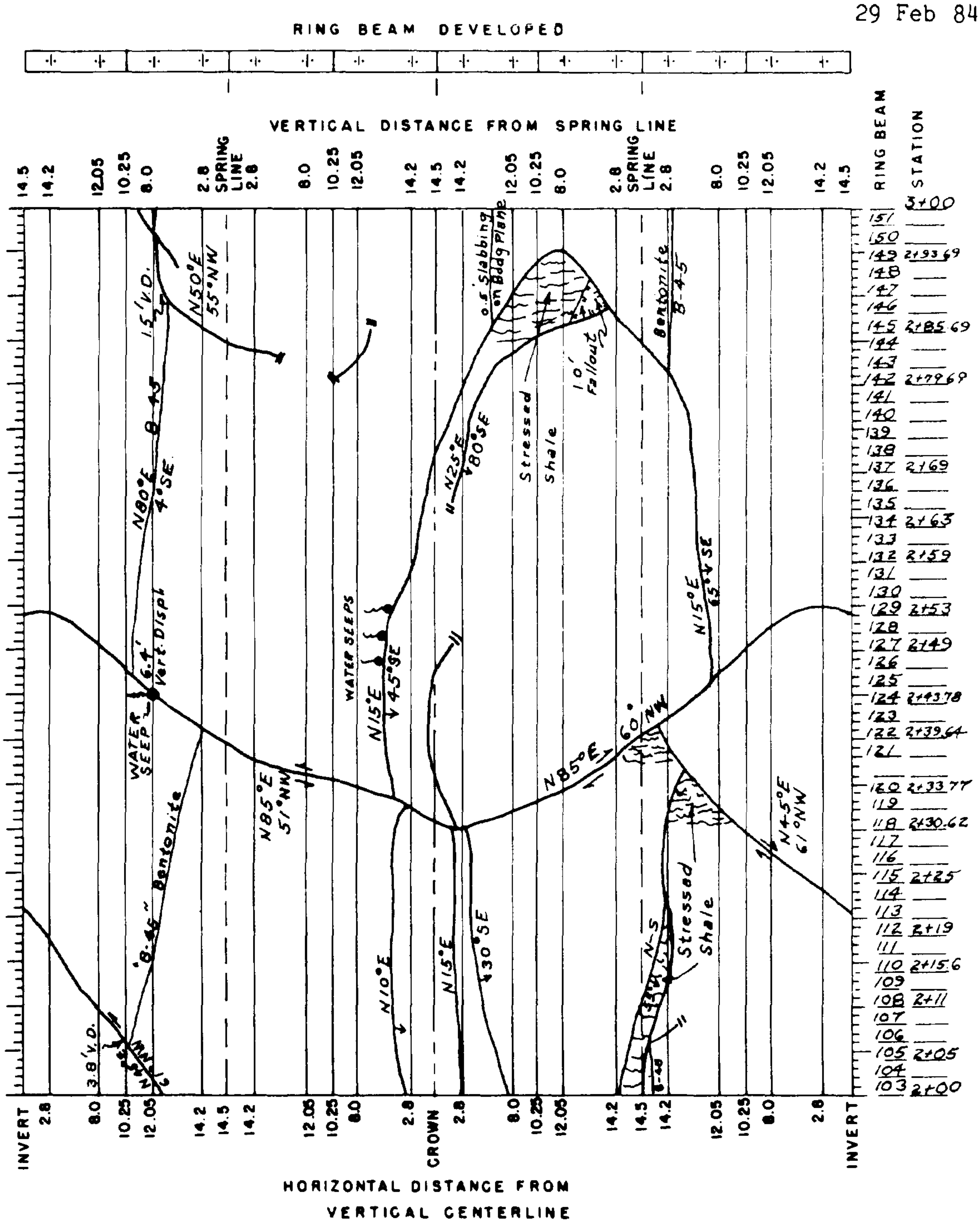


Figure C-1. Preparation of developed plan from a cylindrical cross section



TUNNEL NO. 4 DIAMETER 22 Ft. STA. 248 To 247

Figure C-2. Developed plan of cylindrical tunnel section, Fort Randall Dam, South Dakota



DOWNSTREAM POWER TUNNEL NO. 2
29.0 Ft. DIA. RING BEAM MONOLITH ___ THRU ___
STRIKE N19°E STA. 2+00 TO 3+00

Figure C-3. Developed plan of cylindrical tunnel section, Oahe Dam, South Dakota is not reliable in most underground work because of the proximity to electrical circuits, reinforcing steel, or support steel. Also in some areas, the rock mass itself may be magnetic. To overcome this problem, an adjustable protractor can be devised. Essentially, it is an instrument for measuring the angle between the trend of a planar geologic defect, as measured in the horizontal plane, and the bearing of the tunnel center line. The protractor is fitted with a revolving pointer, which rotates around the center point of the protractor. The baseline of the protractor is held parallel to the tunnel center line, the pointer is sighted along the strike of the discontinuity, and the angle is read on the protractor at the point where a line scribed on the pointer coincides with the degree lines on the protractor arc (fig. C-4). The strike of the geologic defect is then computed from the observed angle and the bearing of the tunnel. In small-diameter drifts, tunnels, adits, etc., a small, light, fixed-base protractor will be adequate for fairly accurate readings. In large-diameter openings, a special protractor may be constructed that has an adjustable baseline. The baseline of the instrument is then revolved to the known tunnel bearing so that direct readings of strike may be taken (fig. C-4). A circular spirit level bubble may be mounted on the instrument to assure that readings are in the horizontal plane. Dip readings are observed by using the inclinometer on a Brunton compass or pocket transit.

C-4. Helpful Suggestions.

a. The geologic features that have the greatest effect on the physical and engineering properties of the rock mass should be logged first. Geologic logging should be performed close to the heading as fresh rock is exposed, before the exposed walls become dust covered or smeared over, and before the geologic features are partially or completely covered by tunnel supports, lagging, pneumatically placed mortar, etc. Mapping should be from the back of the mining machine or on the drill jumbo to help the mapper reach the higher sidewalls and crown in large-diameter tunnels. The main geologic features, such as faults, joints, shear zones, bedding planes, and clay seams, should be carefully plotted first. Then as time permits, other less important features may be filled in between the previously plotted features on the geologic log. Additional features to be logged include fractures, stressed zones, fallouts, water seeps, etc. These features make up only a partial list because additional important geologic features will be encountered at each specific project.

b. In large- and medium-diameter tunnels consecutive mapping sections may be printed on a long sheet of paper to form a scroll. This continuous length of paper can be carried on a mapping board so designed that only the section being mapped is exposed while the remainder of the roll is inclosed in boxes on each side of the mapping board. Cranks and rollers may be added to assist in moving the proper section onto the

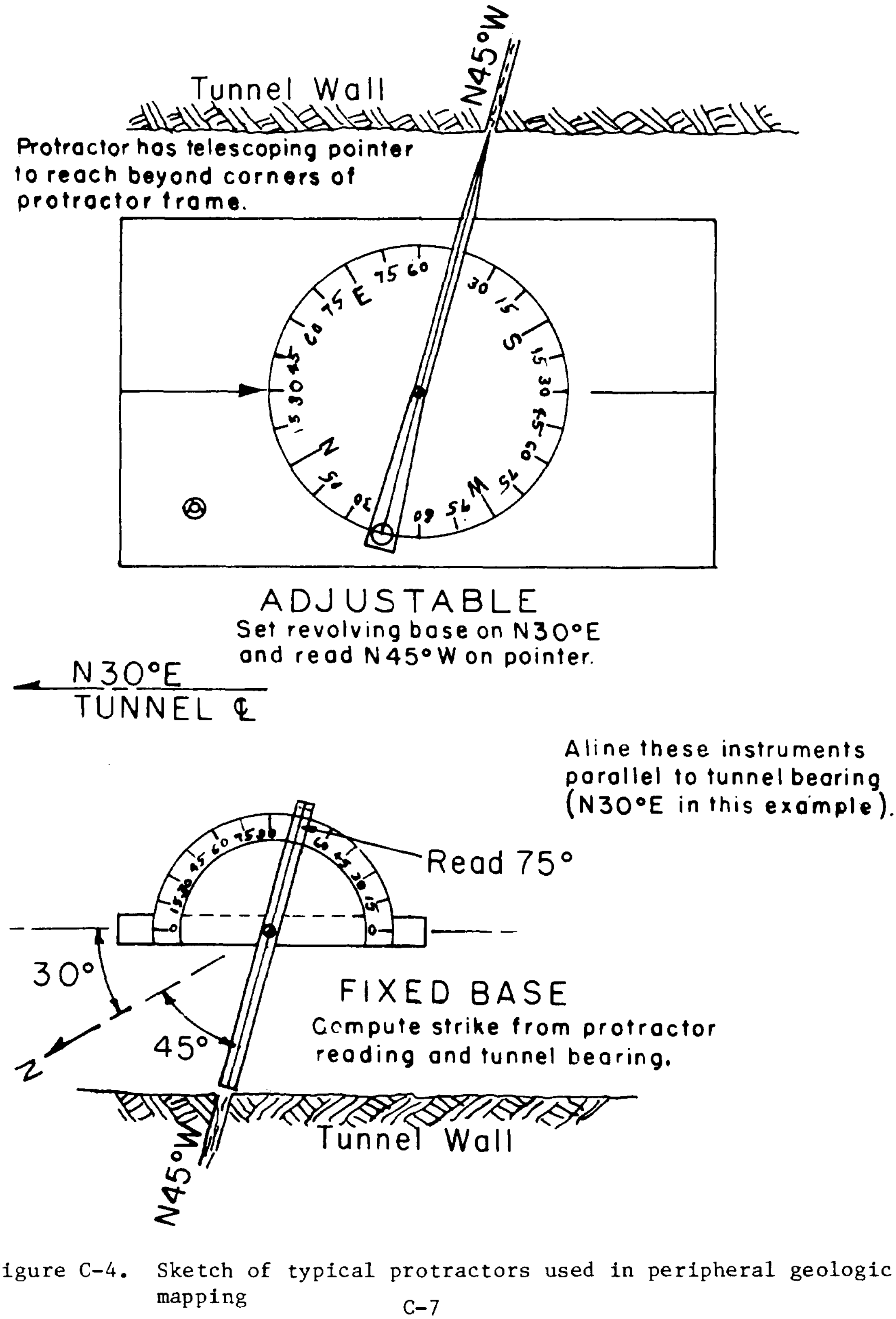


Figure C-4. Sketch of typical protractors used in peripheral geologic mapping

mapping board. The board may be faced with a piece of sheet metal to provide a smooth writing surface. In small or odd-shaped tunnels or drifts the mapping sheets are usually carried in individual conveniently sized sections. A covered clipboard makes a good mapping board. The cover is to protect the mapping sheets from the ever present dust, moisture, etc., associated with underground excavations. If it is necessary for the mapper to extend his own control from known points, a steel tape is stretched along the tunnel and 5- or 10-ft station intervals may be marked on the wall or supports with an aerosol can of spray paint. Photographs of important or unusual geologic features are a valuable addition to the mapping. It is also suggested that a small portable tape recorder for noting the location and attitude of secondary features will help the mapper, especially when adding secondary features to the mapping when time in the tunnels is limited.

c. The completed geologic log of a horizontal or nearly horizontal tunnel will wrap around a mold of proper dimensions to form a model with the mapped features and recorded information in their proper position; however, the geologic log of peripheral mapping in a vertical shaft or end face will not be in its proper position unless the information is traced through the paper to reverse the image. The reversal of the image presents no particular problem since in most instances the field maps and data are transcribed to finished drawings in the office. The geologic section in figure C-5 was not reversed; therefore the observer appears to be in the shaft looking outward. Also in odd-shaped raises or in vertical shafts, it is difficult for the mapper to remain properly oriented unless vertical reference points around the periphery have been surveyed-in prior to the start of geologic mapping.

C-5. <u>Analysis of Data.</u>

a. Although peripheral geologic logging, or mapping, provides a permanent record of all geologic defects exposed on the walls of an underground excavation, maximum benefits cannot be gained unless the data are properly studied and analyzed. One study method is by cutting and trimming the drawings and forming them into the proper shape for three-dimensional viewing, which causes the relationship of discontinuities to the tunnel geometry to become much more apparent.

b. Projection of the trace of geologic discontinuities to two-dimensional plans or profiles may be made, but not directly because the mapping has been done on a developed plan. One method of transferring data to plan is by plotting to corresponding stationing. Data may be transferred to profile, or cross section, by plotting the points where the discontinuities intersect measured stationing at crown, invert, and/or springline. Where only one point can be plotted, the trace of the discontinuity may be extended along a line drawn on the recorded strike or dip of a discontinuity (the use of apparent dip may also be

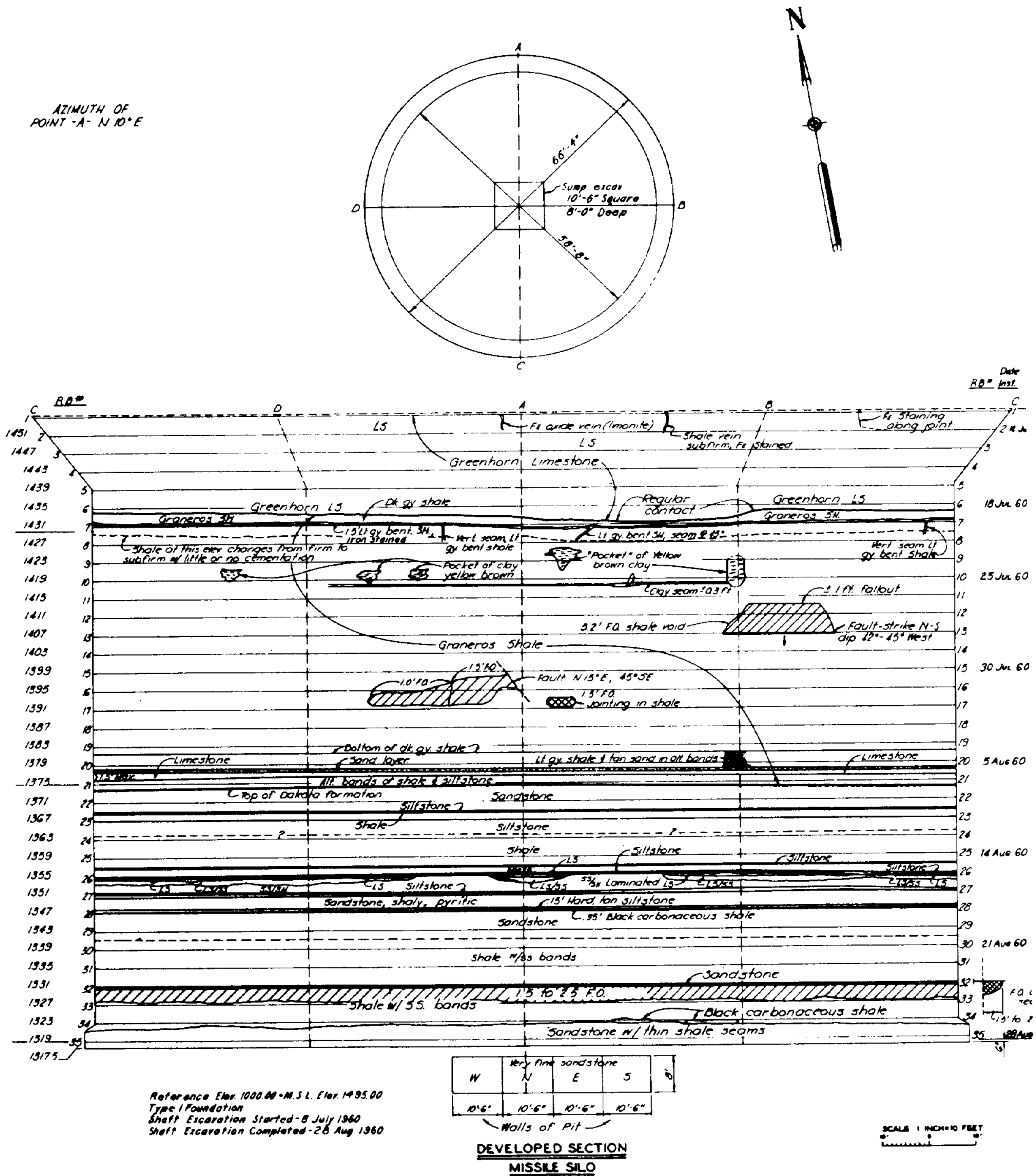


Figure C-5. Developed plan of a large-diameter, vertical, circular shaft necessary). Figure C-6 illustrates a method of projecting geologic data to sections drawn through a circular tunnel.

c. Statistical studies may be made from the accumulated data. By counting all discontinuities per unit of length and circumference, an average piece size or block size may be determined. Plotting the trends of joints, faults, and shears on equal-area nets will help determine the major and minor joint sets and the preferred orientation of faults and shear zones. Another method of statistical analysis might be by making rosette plots of the joints and shears.

C-6. Uses for Geologic Data. The value of peripheral geologic mapping has been proven many times. Below are listed some of the uses for this type of geological logging.

a. Predicting geologic conditions in intermediate tunnels when driving a series of parallel tunnels.

b. Projecting geology from the pilot drift to the full bore of a tunnel before enlarging is started.

c. Planning tunnel support systems and selecting the best location and inclination of supplemental rock bolts.

d. Maintaining a record of difficult mining areas, overbreak and fallout, and mining progress by daily notation of the heading station. This type of record is valuable in changed condition claims.

e. Comparing cracking of concrete tunnel liners with weaknesses logged in tunnel walls.

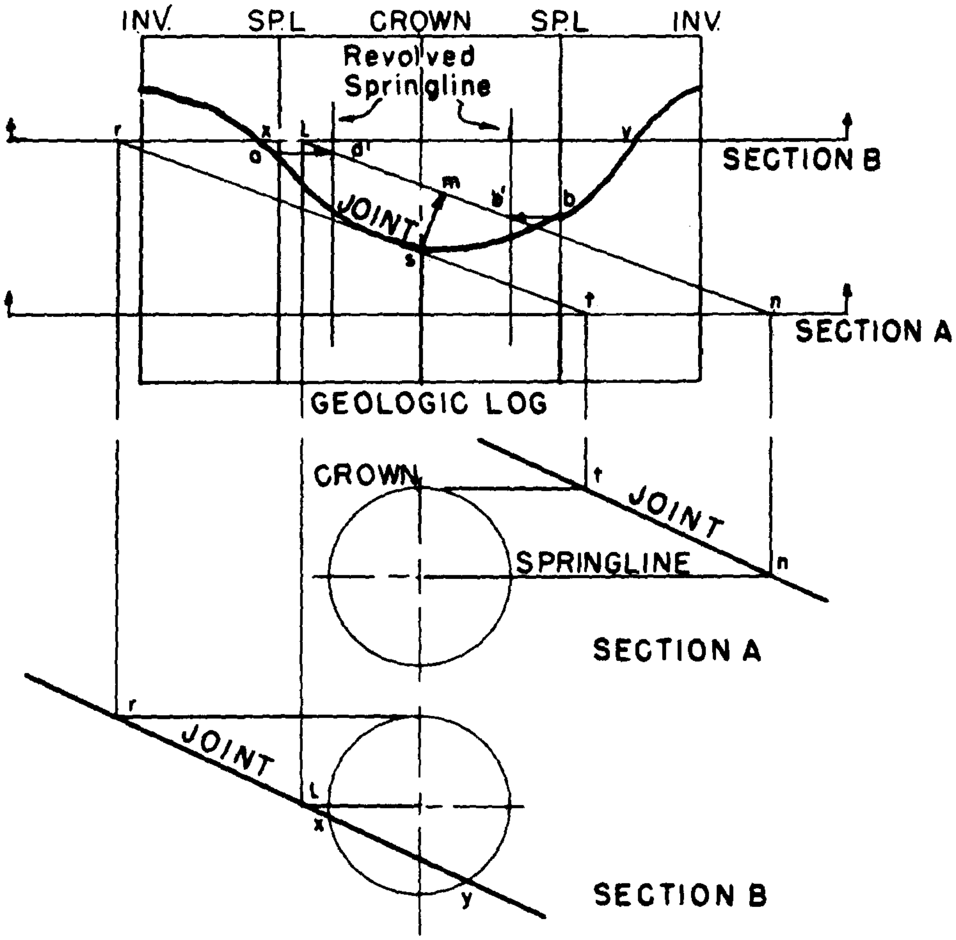
f. Analyzing stress conditions around tunnel openings using methods that evaluate the spacing and orientation of geologic discontinuities.

g. Choosing strategic locations for various types of instrumentation to study tunnel behavior.

h. Selecting the best locations for pore pressure-type piezometer tubes when it is desirable to position them to intercept particular types of discontinuities at specific elevations near previously driven tunnels.

C-7. Examples.

a. The preceding description of peripheral geologic mapping was based primarily on logging, which was done in circular, nearly horizontal tunnels and vertical circular shafts. With some modifications



1. The strike in relation to the tunnel can be found by three different methods:
   a. Revolve springline to tunnel diameter and measure strike a'b'.
   b. Measure tangent to curve at the crown;
   c. Use measured strike.
2. Project the intersection of the strike at the crown (s) to sections desired. For example, joint is at crown level at t and r respectively in sections A & B.
3. Project the strike of the joint at springline level to the section desired; in the example, the joint is at springline elevation at points n and L respectively in sections A and B.
4. Line tn is the trace of the plane on section A. Line rl is the trace of the plane on section B.

   Note: Points x and y show where the joint plane intersects the tunnel boundary in section B. It does not intersect the boundary in section A.
5. Find dip (δ) from distance sm. $\delta = \tan^{-1}\left(\frac{\text{tunnel radius}}{sm}\right)$, or use dip measured in the field.

Figure C-6. Method of projecting geologic data to cross sections from geologic log as developed by R. E. Goodman, University of California and a degree of ingenuity the method can be adapted to almost any shape of underground opening. For some projects the preplanned developed layouts may have to be made by using patterns taken from heating and cooling ductwork manuals.

b. The following illustrations, figures C-7 through C-9, are offered for guidance only. The method may be modified to fit anticipated conditions peculiar to a specific project. For example, in figure C-8, only the curved portion above springline was laid out on a developed plan and the vertical sidewalls below springline were laid out on true scale. No provisions were made for mapping the drift floor since it would not be cleaned sufficiently to expose the geological features.

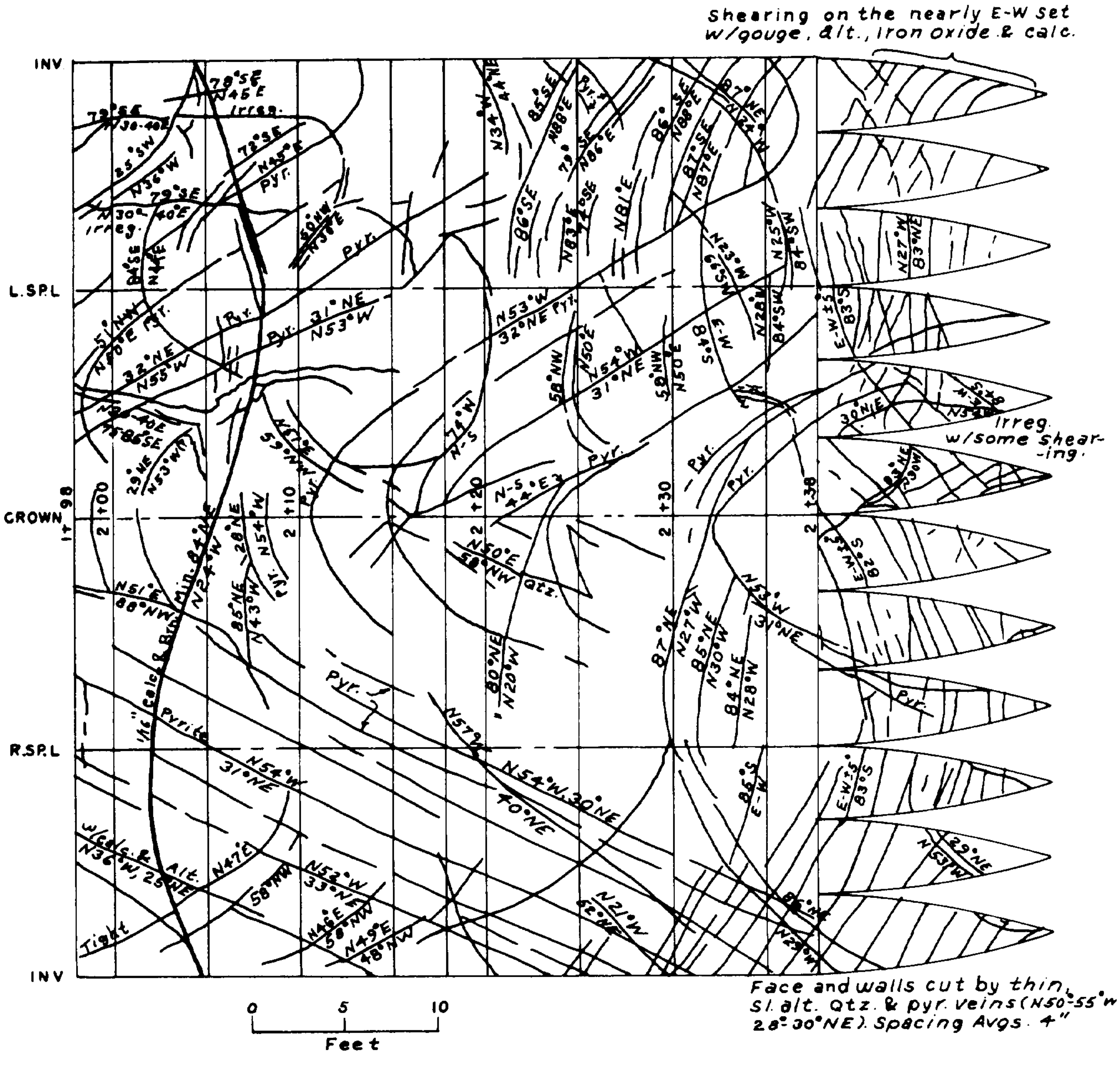


Figure C-7. Developed plan of a cylindrical drift with a hemispherical end section

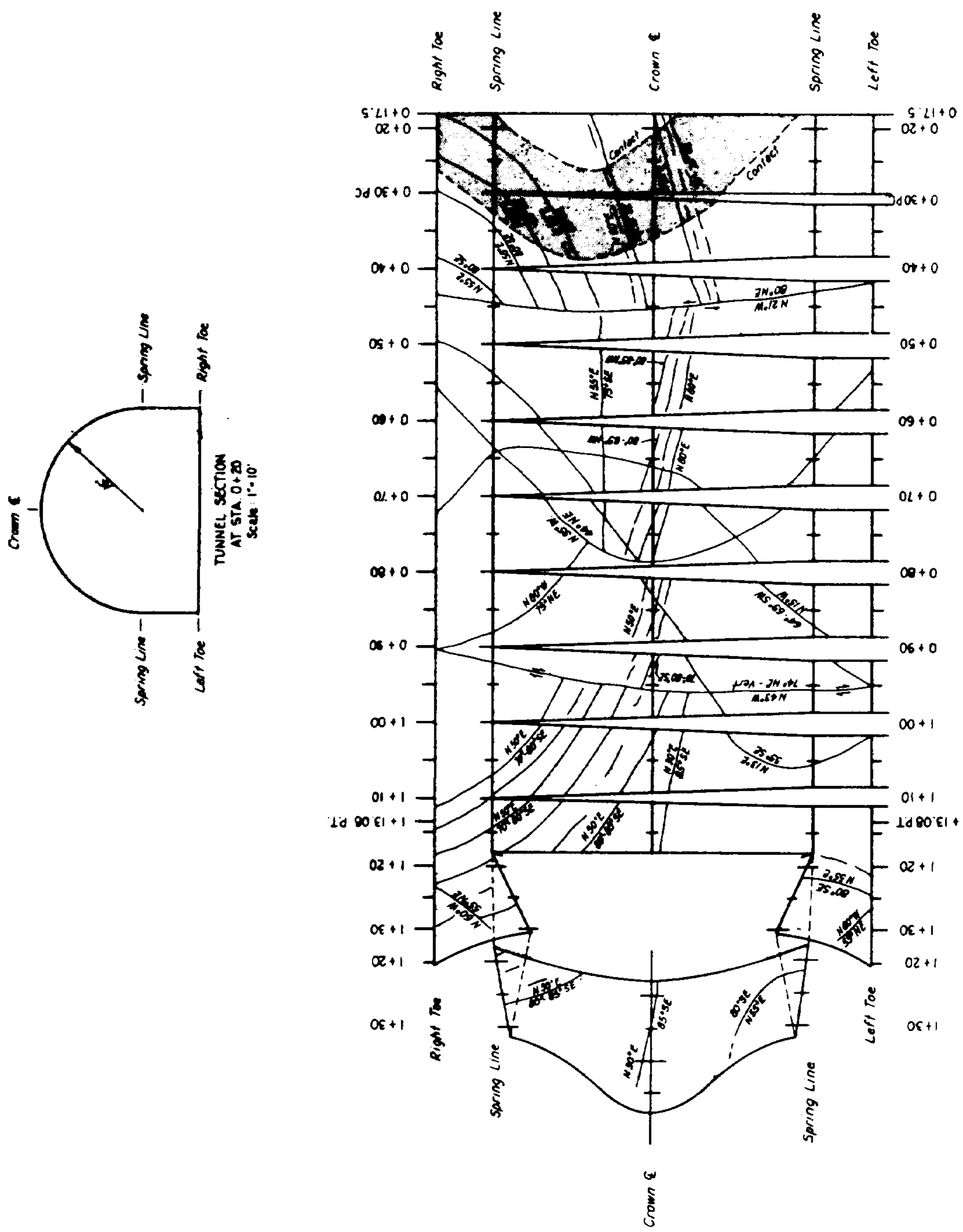


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Figure C-8. Developed plan of a horseshoe-shaped drift with a curved center line and a transition to a larger drift

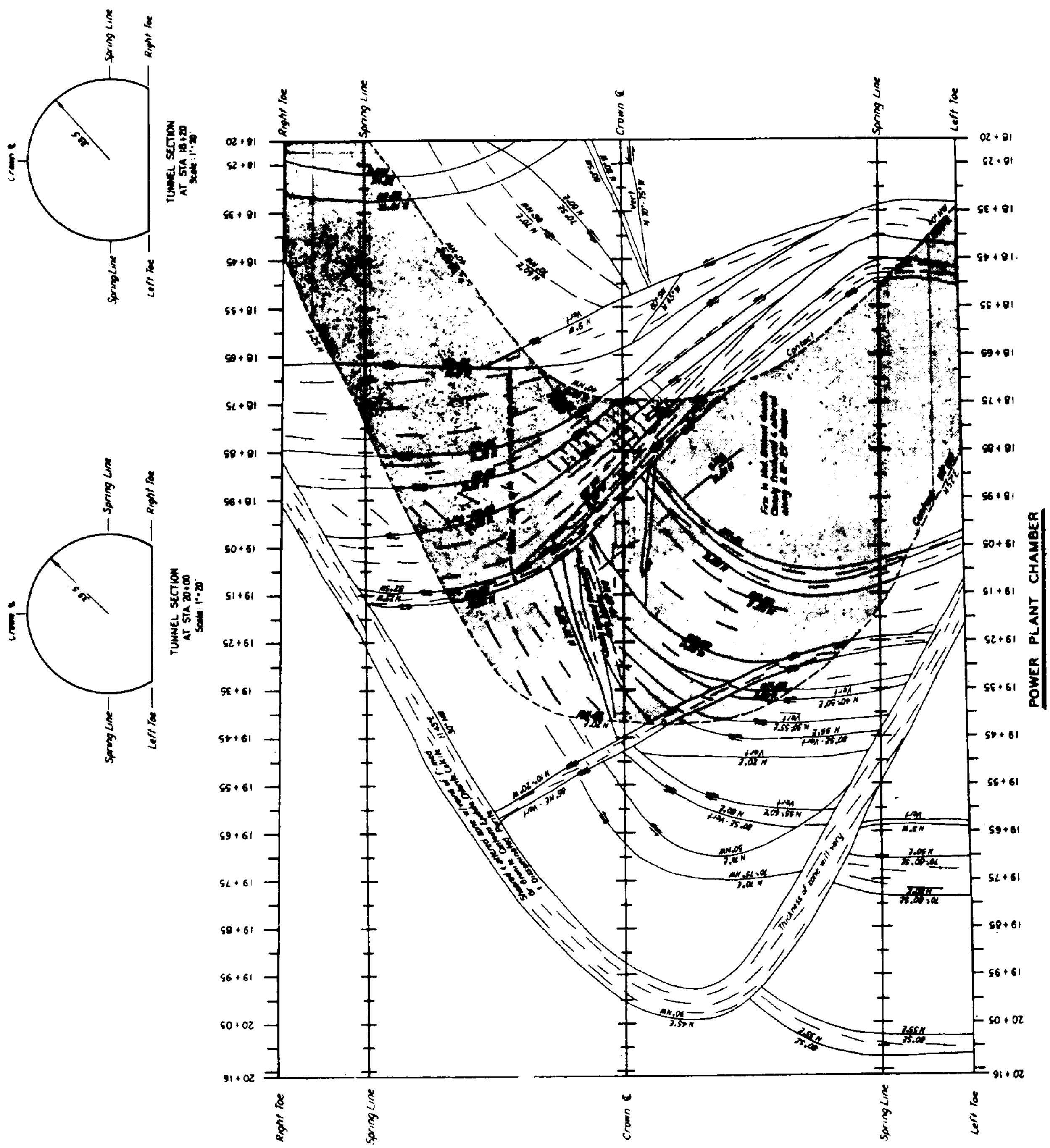


Figure C-9. Developed plan of a horseshoe-shaped large-diameter drift

APPENDIX D
EXAMPLES OF DRILLING LOGS

D-1. General. This appendix contains seven examples of drilling logs, five for overburden drilling and two for rock coring. These logs conform to the guidance presented in EM 1110-1-1806, "Presenting Subsurface Information in Contract Plans and Specifications," and in Chapter 4 of this manual. The examples are not meant to cover all possible subsurface conditions which may be encountered during field investigation, but are presented to give direction to the minimum acceptable input to completing drilling logs for the most common drilling activities.

D-2. Preparation of Drilling Logs. Drilling logs will be made of each boring. A similar log will be prepared for each excavation which is constructed for the purpose of characterizing subsurface materials and geologic conditions. The only approved drilling log form for borings is ENG FORM 1836 (March 1971). This form may be used as a continuation sheet or, at the option of the user, ENG FORM 1836-A (June 1967) may be used. All logs will be filled out in the inspector's own handwriting.

a. Scale. A scale of 1 in. equals 2 ft or larger will be used. A smaller scale may be used where, for example, the boring is advanced without sampling or logging, the upper portion of the log would represent water, or the boring was made to identify some geologic horizon such as top of rock. Other similar exceptions would be allowable.

b. Heading. All logs will have the pertinent division, installation, hole number, project identification, and page number entered on all log sheets. Items 1 through 19, ENG FORM 1836 will be completed to the fullest extent possible as indicated in the seven examples. Boring numbers will be consecutive for each project. The boring numbers will be proceeded by letter symbols which will identify the method of drilling. These letters are as follows:

A - Auger (Hand or Power)

C - Core

D - Drive

P - Probe

T - Test Pit

U - Undisturbed (Hydraulic or Rotary)

Additional letters and numbers for boring identification may be used at the user's discretion. Inclusion of the graphic soil symbol in column c is optional.

c. Examples. The drilling log examples, Figures D-1 through D-7, are described as follows:

Figure D-1: Overburden, disturbed, standard penetration test and auger.

Figure D-2: Overburden, disturbed, drive.

Figure D-3: Overburden, disturbed, auger.

Figure D-4: Overburden, undisturbed, Denison.

Figure D-5: Overburden, undisturbed, Shelby and auger.

Figure D-6: Bedrock, disturbed, SPT and core.

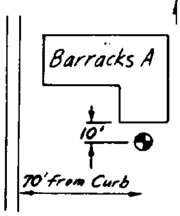
Figure D-7: Bedrock, core.

Hole No. AD-6

DRILLING LOG	DIVISION SAD	INSTALLATION SAS	SHEET 1 OF 2 SHEETS

1. PROJECT: Raymond AFB, S.C. Airmens Dorm	10. SIZE AND TYPE OF BIT: 1 3/8" I.D. Splitspoon
2. LOCATION (Coordinates or Station): See Remarks	11. DATUM FOR ELEVATION SHOWN (TBM or MSL): MSL (NVGD)
3. DRILLING AGENCY: SAS	12. MANUFACTURER'S DESIGNATION OF DRILL: Failing 314
4. HOLE NO. (As shown on drawing title and file number): AD-6	13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN: DISTURBED 26 Jars; UNDISTURBED
5. NAME OF DRILLER: S. Long	14. TOTAL NUMBER CORE BOXES: —
6. DIRECTION OF HOLE: [X] VERTICAL [ ] INCLINED ____ DEG. FROM VERT.	15. ELEVATION GROUND WATER: 17.5
7. THICKNESS OF OVERBURDEN: 30.0	16. DATE HOLE: STARTED 3 Apr. 81; COMPLETED 4 Apr. 81
8. DEPTH DRILLED INTO ROCK: 0	17. ELEVATION TOP OF HOLE: 25.5
9. TOTAL DEPTH OF HOLE: 30.0	18. TOTAL CORE RECOVERY FOR BORING: N/A %
	19. SIGNATURE OF INSPECTOR: Cindy Watson

ELEVATION (a)	DEPTH (b)	LEGEND (c)	CLASSIFICATION OF MATERIALS (Description) (d)	% CORE RECOVERY (e)	SAMPLE NO. (f)	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) (g) Std. Pene. Test BLOWS
23.0	0–2.5		(SM) Brown, Silty SAND Roots In Top 6".		NS, 1, NS, 2	NS = No Sample; 1, 2, 4, 2, 5
19.9	2.5–5.6		(SP-SM) Light Brown, Poorly Graded, Silty SAND, Medium To Fine, Traces Of Shell, Moist.		3, NS, 4, NS, 5	6, 3, 6, 9, 4, 8
	5.6–10		(SP) Light Brown, Poorly Graded SAND, Fine w/ Traces Of Shell		6, NS, 7	10, 3, 10, 12
▼ El 17.5 4/4/81; 15.5	8		Light Gray		NS, 8, NS, 9	▼ Encountered Water During Drilling With 5" Auger - Mixed Mud At 8' & Cleaned Boring With 4" Rock Bit; 5, 8, 13, 6, 7
14.5	10–11		(OL) Dark Gray To Black, Organic SILT, Trace Sand, Strong Odor.		10, NS	3, 1
12.5	11–13		(OH) Black, Organic SILT, Lenses Of Clay, Strong Odor, Peaty.		11, NS, 12	2, 2, 0, 4
11.1	13–14.4		(SM) Dark Gray, Silty SAND, Medium To Fine.		13, NS, 14	9, 5, 13
7.0	14.4–18.5		(SP) Light Brown, Poorly Graded SAND, Fine.		15, NS, 16, NS, 17, NS	18, 8, 15, 18, 6, 13, 22, 8
	18.5–20		(SP) Light Gray, Poorly Graded SAND, Medium To Coarse.		18, NS	9, 10, 7



LOCATION PLAN

ENG FORM 1836 MAR 71 PREVIOUS EDITIONS ARE OBSOLETE (TRANSLUCENT)

PROJECT: Raymond AFB - Airmens Dorm | HOLE NO. AD-6

Figure D-1. Example drilling log, for auger boring in overburden with disturbed sampling and standard penetration tests (Continued)

Hole No. AD-6

DRILLING LOG	DIVISION SAD	INSTALLATION SAS	SHEET 2 OF 2 SHEETS

1. PROJECT Raymond AFB, Airmens Dorm	10. SIZE AND TYPE OF BIT
2. LOCATION (Coordinates or Station)	11. DATUM FOR ELEVATION SHOWN (TBM or MSL)
3. DRILLING AGENCY	12. MANUFACTURER'S DESIGNATION OF DRILL
4. HOLE NO. (As shown on drawing title and file number) AD-6	13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN — DISTURBED — UNDISTURBED
5. NAME OF DRILLER	14. TOTAL NUMBER CORE BOXES
6. DIRECTION OF HOLE ☐ VERTICAL ☐ INCLINED ____ DEG. FROM VERT.	15. ELEVATION GROUND WATER
	16. DATE HOLE — STARTED — COMPLETED
7. THICKNESS OF OVERBURDEN	17. ELEVATION TOP OF HOLE 25.5
8. DEPTH DRILLED INTO ROCK	18. TOTAL CORE RECOVERY FOR BORING %
9. TOTAL DEPTH OF HOLE	19. SIGNATURE OF INSPECTOR Cindy Watson

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	~~BOX OR~~ SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
			(SP) Light Gray, Poorly Graded SAND, Medium To Coarse.		19	15 / 19
					NS	6
	22				20	20 / 25
					NS	10
					21	20
2.0	24		Gravelly		22	25
1.0					NS	11
			(CL) Brownish Gray, Sandy CLAY, Stiff To Hard, Shelly, Moist.		23	15 / 30
	26				NS	10
					24	18 / 32
					NS	11
	28				25	15 / 26
					NS	8
-4.5	30				26	21 / 50
			Bottom Of Boring			

ENG FORM 1836 MAR 71 PREVIOUS EDITIONS ARE OBSOLETE (TRANSLUCENT) | PROJECT Raymond AFB, Airmens Dorm | HOLE NO. AD-6

Figure D-1. (Concluded)

Hole No. D-18

DRILLING LOG	DIVISION Missouri River	INSTALLATION Kansas City	SHEET 1 OF 5 SHEETS

1. PROJECT: Grove Dam
2. LOCATION (Coordinates or Station): 42+00 on ℄
3. DRILLING AGENCY: Kansas City Dist.
4. HOLE NO. (As shown on drawing title and file number): D-18
5. NAME OF DRILLER: C. Brown
6. DIRECTION OF HOLE: ☑ VERTICAL ☐ INCLINED ____ DEG. FROM VERT.
7. THICKNESS OF OVERBURDEN: 95.0
8. DEPTH DRILLED INTO ROCK: 0
9. TOTAL DEPTH OF HOLE: 95.0 (El 620.0)
10. SIZE AND TYPE OF BIT: 3" ϕ, Drive Barrell
11. DATUM FOR ELEVATION SHOWN (TBM or MSL): NGVD
12. MANUFACTURER'S DESIGNATION OF DRILL: Walker Neer Cable Tool
13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN: DISTURBED 48 Jars; UNDISTURBED
14. TOTAL NUMBER CORE BOXES:
15. ELEVATION GROUND WATER: 698.0
16. DATE HOLE: STARTED 6 Jan 78; COMPLETED 12 Jan 78
17. ELEVATION TOP OF HOLE: 715.0
18. TOTAL CORE RECOVERY FOR BORING: N/A %
19. SIGNATURE OF INSPECTOR: John Doe

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	~~BOX OR~~ SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
714.0			Asphalt and Base Course		1	Rec 2.0 15 Blows
	2		(CL) Tan, Lean CLAY, Enbankment Fill		2	Rec 2.0 16 Blows
	4				3	Rec 2.0 14 Blows
	6				4	Rec 2.0 18 Blows
	8				5	Rec 2.0 20 Blows
	10				6	Rec 1.9 Loss 0.1 14 Blows
	12				7	Rec 2.0 18 Blows
701.0	14		Slightly Sandy		8	Rec 2.0 Ream to 16.0' 22 Blows
▼698.0± 12 Jan 78	16		Static Water Level After Completion Of Boring.		9	Rec 1.9 Loss 0.1 21 Blows
	18				10	Rec 2.0 23 Blows
	20					

ENG FORM 1836 MAR 71 PREVIOUS EDITIONS ARE OBSOLETE (TRANSLUCENT) | PROJECT | HOLE NO. D-18

Figure D-2. Example drilling log (partial) for drive boring in overburden with disturbed sampling

Hole No. A-30

DRILLING LOG	DIVISION SWD	INSTALLATION SWT	SHEET 1 OF 1 SHEETS
1. PROJECT SR 9 Road Relocation Eufaula Lake		10. SIZE AND TYPE OF BIT 4 in. Square Auger	
2. LOCATION (Coordinates or Station) Station 4+50, 50' Rt.		11. DATUM FOR ELEVATION SHOWN (TBM or MSL) NGVD	
3. DRILLING AGENCY Tulsa Dist.		12. MANUFACTURER'S DESIGNATION OF DRILL CME-1200	
4. HOLE NO. (As shown on drawing title and file number) A-30		13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN	DISTURBED 2 / UNDISTURBED —
5. NAME OF DRILLER A. Jones		14. TOTAL NUMBER CORE BOXES —	
6. DIRECTION OF HOLE [X] VERTICAL [ ] INCLINED ___ DEG. FROM VERT.		15. ELEVATION GROUND WATER Not Encountered	
7. THICKNESS OF OVERBURDEN 8.2		16. DATE HOLE	STARTED 8-29-82 / COMPLETED 8-29-82
8. DEPTH DRILLED INTO ROCK —		17. ELEVATION TOP OF HOLE 816.2	
9. TOTAL DEPTH OF HOLE 8.2 (El 808.0)		18. TOTAL CORE RECOVERY FOR BORING — %	
		19. SIGNATURE OF INSPECTOR Gane Smith	

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
	0–3		(CL) Brown, Sandy Lean CLAY, Moist		Jar 1	Drilled With 4 in. Square Auger. No Free Water Encountered. Refusal to Auger At 8.2', Hydraulic Pressure 100 PSI With No Penetration For 2 Min. At Refusal. Drilled 0-8' In 4 Min. Drill rate 2'/Min. Drill Action Smooth At 100 RPM
813.2	3		(ML) Tan, Clayey, SILT, Slightly Plastic			
	5		Micaceous, Slightly Damp		Jar 2	
808.0	8.2		Refusal To Auger @ 8.2'			

ENG FORM 1836 MAR 71 PREVIOUS EDITIONS ARE OBSOLETE (TRANSLUCENT)

PROJECT SR9 Road Relocation Eufaula Lake | HOLE NO. A-30

Figure D-3. Example drilling log for auger boring in overburden with disturbed samples

Hole No. U-1

DRILLING LOG	DIVISION SAD	INSTALLATION SAS	SHEET 1 OF 1 SHEETS

1. PROJECT: Richard B. Russell Dam	10. SIZE AND TYPE OF BIT: 6 in. Denison
2. LOCATION (Coordinates or Station): X: 312,457 Y: 123,456	11. DATUM FOR ELEVATION SHOWN (TBM or MSL): NGVD
3. DRILLING AGENCY: SAS	12. MANUFACTURER'S DESIGNATION OF DRILL: Failing 1500
4. HOLE NO. (As shown on drawing title and file number): U-1	13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN: DISTURBED — UNDISTURBED 17
5. NAME OF DRILLER: J. Smith	14. TOTAL NUMBER CORE BOXES: —
6. DIRECTION OF HOLE: ☑ VERTICAL ☐ INCLINED ____ DEG. FROM VERT.	15. ELEVATION GROUND WATER: See Remarks
	16. DATE HOLE: STARTED 3-16-75 COMPLETED 3-16-75
7. THICKNESS OF OVERBURDEN: 36.2	17. ELEVATION TOP OF HOLE: 376.5
8. DEPTH DRILLED INTO ROCK: 0	18. TOTAL CORE RECOVERY FOR BORING: N/A %
9. TOTAL DEPTH OF HOLE: 36.2 (El 340.3)	19. SIGNATURE OF INSPECTOR: Johnny Jones

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	~~% CORE RECOVERY~~ HAND PENE TSF e	~~BOX OR~~ SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
			(ML) Reddish Brown, Slightly Clayey, SILT.			Fish Tailed To 2'. Drilled With 6 in. Denison Barrel With Inner Barrel Protruding 1 in. 100 % Recovery Except As Noted. Hand Penetrometer Made On Bottom Of Each Sample. No Changes In Drill Mud To Indicate Free Water.
				0.6	1	
	5			0.5	2	
				0.5	3	
				0.6	4	
	10			0.4	5	
				0.5	6	#6 Ran 2.0 Rec 1.6
	15			0.6	7	
				0.6	8	
				0.7	9	
	20			0.6	10	#10 Ran 2.0 Rec 1.8
				0.6	11	#11 Ran 2.0 Rec 1.6
	25		Red, Slightly Sandy	0.8	12	
				0.9	13	
	30			0.8	14	#14 Ran 2.0 Rec 1.2
				0.9	15	
				1.0	16	
340.3	35		Bottom Of Hole	0.9	17	Refusal At 36.2' No Recovery 36.0'-36.2'

ENG FORM 1836 MAR 71 PREVIOUS EDITIONS ARE OBSOLETE (TRANSLUCENT) PROJECT Richard B. Russell Dam HOLE NO. U-1

Figure D-4. Example drilling log for Denison sample boring in overburden

Hole No. AU-3

DRILLING LOG	DIVISION ORD	INSTALLATION Huntington	SHEET 1 OF 1 SHEETS
1. PROJECT Alum Creek Dam, Ohio		10. SIZE AND TYPE OF BIT 6 in Auger & 5 in Shelby	
2. LOCATION (Coordinates or Station) Sta. 2+50.0 5 D/S of ℄		11. DATUM FOR ELEVATION SHOWN (TBM or MSL) NGVD	
3. DRILLING AGENCY ORH		12. MANUFACTURER'S DESIGNATION OF DRILL Failing 1500	
4. HOLE NO. (As shown on drawing title and file number) AU-3		13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN	DISTURBED — UNDISTURBED 3
5. NAME OF DRILLER C. Black		14. TOTAL NUMBER CORE BOXES —	
6. DIRECTION OF HOLE ☑ VERTICAL ☐ INCLINED ____ DEG. FROM VERT.		15. ELEVATION GROUND WATER Not Encountered	
7. THICKNESS OF OVERBURDEN —		16. DATE HOLE	STARTED 6 May 1981 COMPLETED 6 May 1981
8. DEPTH DRILLED INTO ROCK —		17. ELEVATION TOP OF HOLE 952.4	
9. TOTAL DEPTH OF HOLE 22.0 (El. 930.4)		18. TOTAL CORE RECOVERY FOR BORING N/A	
		19. SIGNATURE OF INSPECTOR William Boyd	

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	~~% CORE RECOVERY~~ e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
				Hand Penet.		Augered w/ 6 in. Helical Auger To 6, 10, And 20 Feet. Where 5 in. Shelby Tubes Were Pushed 24 in.
	5			1.0 TSF	U-1	Hand Penetrometer Taken On Lower End Of Each Sample
	10			1.6 TSF	U-2	Push 1 Ran 24" Rec 24"
	15					Push 2 Ran 24" Rec 24"
	20					Push 3 Ran 24" Rec 24"
930.4			Bottom Of Boring	2.0 TSF	U-3	24.0'

ENG FORM 1836 MAR 71 PREVIOUS EDITIONS ARE OBSOLETE. (TRANSLUCENT)

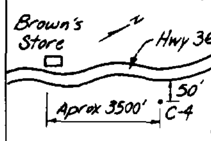
PROJECT Alum Creek Dam, Ohio | HOLE NO. AU-3

Figure D-5. Example drilling log for auger boring in overburden with Shelby tube sampling

Hole No. DC-4

DRILLING LOG | DIVISION: South Pacific | INSTALLATION: Los Angeles | SHEET 1 OF 42 SHEETS

1. PROJECT: PRADO DAM, CA
2. LOCATION (Coordinates or Station): See Remarks
3. DRILLING AGENCY: Mott Drilling Co
4. HOLE NO. (As shown on drawing title and file number): DC-4
5. NAME OF DRILLER: Horton
6. DIRECTION OF HOLE: ☑ VERTICAL ☐ INCLINED ______ DEG. FROM VERT.
7. THICKNESS OF OVERBURDEN: 5.0 (575.0)
8. DEPTH DRILLED INTO ROCK: 100.0
9. TOTAL DEPTH OF HOLE: 475.0
10. SIZE AND TYPE OF BIT: Diamond NWM $1\frac{3}{4}$" I.D.S.S.
11. DATUM FOR ELEVATION SHOWN (TBM or MSL): MSL
12. MANUFACTURER'S DESIGNATION OF DRILL: Sullivan - 180
13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN: DISTURBED 4 | UNDISTURBED
14. TOTAL NUMBER CORE BOXES: 14
15. ELEVATION GROUND WATER: See Remarks
16. DATE HOLE: STARTED 2/18/79 | COMPLETED 3/18/79
17. ELEVATION TOP OF HOLE: 575.0
18. TOTAL CORE RECOVERY FOR BORING: 99.4 / 99.5 %
19. SIGNATURE OF INSPECTOR: Jim Jones

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g — Std. Pene. Test Blows
573.5	1		(CL) Brown, Sandy CLAY, Roots In Top 6", Moist		1	 5 7 8
	2, 3		(SC) Brown, Clayey, SAND, Fine To Medium, Moist		2	Drl w/ 1.1' x $4\frac{1}{2}$" Rollar Rock Bit w/ Water Begin 1300 End 1350 — 4 6 13
570.5	4				3	Ran 5.0' Set 5.3' of 4" Black Iron Pipe 1 w/ Saw Tooth End To 5.0' — 8 11 11
570.0	5		Rock Frags TR		4	Ref At 5.0' — 50
	6, 7, 8, 9, 10		SANDSTONE - Mss Bdd, Sl, Mic, Med Hd To Hd, F To Med Gra, Lt Gr To Lt Br, Occ Blk Sh Ptgs, Num Hem Ptgs upper 3' Of Core So To Med Hd, Vf. 0.6 LC So, St Red Op. h/a Jt, 55°	Rec 84% RQD 79%	Box 1 Of 10 Boxes	Drl w/ 11.7 (10.3) NXM Bit # 1234 (V. Good) Shell # 5678 (New) Pull 1 Drl Tools 21.7' WL 7.6' @ 1640 Began 1615 End 1635 Drl Time 20 Min Ran 5.2 Rec 3.8 Loss 1.4 U.L. 0.6 Water Pressure 50psi Drl Action - Smooth 100 % DWR - 100% CD 9.4' Tape RQD $\frac{3.5'}{9.4'}$ = 0.79%

ENG FORM 1836 MAR 71 PREVIOUS EDITIONS ARE OBSOLETE (TRANSLUCENT) | PROJECT: Prado Dam, Ca. | HOLE NO: DC-4

Figure D-6. Example drilling log for core boring into bedrock with SPT, disturbed samples and rock cores (Continued)

DRILLING LOG (Cont Sheet) ELEVATION TOP OF HOLE 575.0 **Hole No.** DC-4

PROJECT PRADO DAM, CA. INSTALLATION Los Angeles SHEET 2 OF 42 SHEETS

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
			SANDSTONE (Cond. As Above)			10.2
						Pull 2
						Drill Tools 31.7'
	11					WL 8.2' @ 1800
						Begin 1645
						End 1745
						Drill Time 1 hr.
	12		Op, 1/4 Jt, 15° St. Red	Rec 93%	Box 1 Of 10 Boxes	Ran 10.0'
						Rec 10.0'
						Loss 0.0'
						U.L. 0.8'
	13		Cav. Op, 0.6' U.L. No DWL			Water Pressure 50psi
				RQD 93%		Drl Action - Smooth
						100% DWR-br
						RQD $\frac{10.0'}{10.8} = 93\%$
	14					Rod Drop 13.0 To 13.6 No DWL, No Change In Color of DWR
	15					
	16		Op, Hor. Jt., Smooth			
	17				17.0	
	18				Box 2 Of 10 Boxes	
	19		0.2' U.L., Spins Prob. Ground During Drilling			
	20					CD TAPE 20.2 20.2
						Pull 3 (Cond. On Next Page)
	21		Num. Fracs. St. Red 0.3' C.L.			
	22					

ENG FORM 1836-A JUN 67   PROJECT PRADO DAM, CA.   HOLE NO DC-4

Figure D-6. (Concluded)

Hole No. C-18

DRILLING LOG	DIVISION: Ohio River	INSTALLATION: Louisville	SHEET 1 OF 3 SHEETS

1. PROJECT: Taylorsville Dam	10. SIZE AND TYPE OF BIT: Dia NWM
2. LOCATION (Coordinates or Station): X: 137,187 F Y: 26,867 F	11. DATUM FOR ELEVATION SHOWN (TBM or MSL): MSL
3. DRILLING AGENCY: Louisville District	12. MANUFACTURER'S DESIGNATION OF DRILL: Failing 314
4. HOLE NO. (As shown on drawing title and file number): C-18	13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN: DISTURBED — UNDISTURBED —
5. NAME OF DRILLER: A. Brown	14. TOTAL NUMBER CORE BOXES: 4
6. DIRECTION OF HOLE: ☑ VERTICAL ☐ INCLINED ____ DEG. FROM VERT.	15. ELEVATION GROUND WATER: 606.5
	16. DATE HOLE: STARTED 11 Aug 76 COMPLETED 16 Aug 76
7. THICKNESS OF OVERBURDEN: 0	17. ELEVATION TOP OF HOLE: 625.5
8. DEPTH DRILLED INTO ROCK: 33.5	18. TOTAL CORE RECOVERY FOR BORING: 93 %
9. TOTAL DEPTH OF HOLE: 33.5' (EL 592.0)	19. SIGNATURE OF INSPECTOR: John Smith

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
			LIMESTONE, Silty, Hard Slightly Weathered To Unweathered, Finely Crystalline, Massively Bedded, Moderately Jointed w/ Tight, Smooth Bedding Plane Joints Dipping 5°, Gray, Vuggy.		Box 1 of 4 Boxes	Bit # 1234 - New Shoe # 456 - Used, Good 5.0' Barrell Pull 1 0-4.5'
	1			Rec 100%		Ran 4.5 Rec 4.5 Loss 0.0
	2		Moderately Weathered, Tan	RQD 100%		Drl. Action Smooth Water Return - 100% Lt. Gray Hyd Press. 100 psi Drill Time 32 min.
	3		Tight High Angle Joints			RQD $\frac{4.5'}{4.5'}$ = 100
	4					C.D. 4.5 4.5
	5					Pull 2 4.5-9.5
			Horizontal Joint, Rough Slightly Open	Rec 91%		Ran 5.0 Rec 4.2 Loss 0.8 U.L. 0.4
	6		Dark Gray, Very Silty	RQD 85%		Drl Action · Rough 7.0'-7.7'
	7		Shattered, Stained Red-Brown, Trace Of Red Clay, 0.4' U.L.			Water Return 100% Reddish Brown 7.0'-9.5' Drl Time 48 min Hyd Press. 150 psi
	8					RQD $\frac{3'11''}{4'7''}$ = 85%
	9		45° Joint, Tight, Smooth		9.1'	CD Tape 9.1 9.5
	10					

ENG FORM 1836 MAR 71 PREVIOUS EDITIONS ARE OBSOLETE (TRANSLUCENT)

PROJECT: Taylorsville Dam HOLE NO. C-18

Figure D-7. Example drilling log for core boring in bedrock (sheet 1 of 3)

DRILLING LOG (Cont Sheet)	ELEVATION TOP OF HOLE 625.5					Hole No. C-18
PROJECT Taylorsville Dam			INSTALLATION Louisville			SHEET 2 OF 3 SHEETS
ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
	10		LIMESTONE (Cont.)			Pull 3 9.5 - 14.0
	11		Numerous Vugs	Rec 100%	Box 2 Of 4 Boxes	Ran 4.5 Rec 4.9 Gain 0.4 Drl. Action Smooth Water Ret. 100% Gray
	12		Horizontal Open Joints	RQD 71%		Drl. Time 62 min. Hyd. Press. 150 psi RQD 3'6" / 4'11" = 71%
	13		Core Badly Broken Numerous Closely Spaced High Angle And Horizontal Joints			
	14		Low Angle (10°) Irregular Joint, Tight 45° Joint, Tight 45° Joint, Slightly Open			CD 14.0 14.0 Pull 4 14.0 - 19.0
	15			Rec 100%		Ran 5.0 Rec 4.5 Loss 0.5 U.L. 0.0 Drl. Action Smooth
	16			RQD 85%		Water Ret. 100% Gray Drl. Time 75 min. Hyd Press. 150 psi
	17					RQD 3'9" / 4'5" = 85%
	18		Irregular, Horizontal Joint, Tight		18.0	CD TAPE 18.5
306.4	19		100% Drill Water Loss		Box 3 Of 4 Boxes	19.0 Pull 5 19.0 - 25.5
	20		Open Cavity, Tools Dropped Freely	Rec 61%		Ran 6.5 Rec 4.0 Loss 2.5 U.L. 2.6
304.3	21		Stained Brown	RQD 53%		Drl. Action - Rough 100% W.L. At 19.1 Drl. Time 40 min. Hyd. Press. 150 psi
	22					

ENG FORM 1836-A (JUN 67)   PROJECT Taylorsville Dam   HOLE NO. C-18

Figure D-7. (Sheet 2 of 3)

DRILLING LOG (Cont Sheet)	ELEVATION TOP OF HOLE 625.5			Hole No. C-18	
PROJECT Taylorsville Dam	INSTALLATION Louisville			SHEET 3 OF 3 SHEETS	

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
	22		LIMESTONE (Cont.)			Pull 5 (Cont.)
			Horizontal Open Joints Stained Brown	Rec 61%	Box 3 of 4 Boxes (Cont.)	RQD $\frac{3'6''}{6'7''} = 53\%$
	23					W.L. In Hole After Run 19.0'
				RQD 53%		
	24					
	25		Fresh, Irregular Break Near Horizontal			CD Tape 25.1 — 25.5
						Pull 6 25.5-29.0
	26			Rec 100%		Ran 3.5 Rec 3.9 Gain 0.4
	27		Fresh Break Along Silty Parting	RQD 100%	27.0	Drl. Action Rough No D.W. Return Hyd. Press. 150 psi Drl Time 40 min.
	28				Box 4 of 4 Boxes	W.L. -19.0' RQD $\frac{3'11''}{3'11''} = 100\%$
	29		45° Joint, Tight, Smooth			CD 29.0
						Pull 7 29.0-33.5
	30			Rec 100%		Ran 4.5 Rec 4.5 Loss 0.0 Drl. Action Rough No D.W. Return
	31		Horizontal Fracture Irregular, Fresh	RQD 100%		Hyd. Press. 150 psi Drl. Time 70 min. W.L. 19.0' RQD $\frac{4'6''}{4'6''} = 100\%$
	32					Water Level 19.0' After 24 Hr.
	33					
592.0			Bottom Of Hole			Tape CD 33.5 — 33.5

ENG FORM 1836-A JUN 67 GPO 1967 OF-267-678 PROJECT Taylorsville Dam HOLE NO. C-18

Figure D-7. (Sheet 3 of 3)

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