PART 1
TEST QUARRIES

Chapter 2
Investigation Stages

2-1. Project Development Phases and Associated Geotechnical Investigations

Table 2-1 shows civil works project development phases and the geotechnical investigations performed during these phases.

ER 1110-2-1150 provides the requirements for each of the project development phases and EM 1110-1-1804 provides detailed discussions of the scope of geotechnical investigations for each phase.

2-2. Reconnaissance Study Phase

A reconnaissance study is fully Federally funded and is conducted to determine whether a problem has solutions acceptable to local interests which are in accordance with administration policy and if planning should proceed to the feasibility phase. The reconnaissance phase is general in scope and the engineering effort should be assessing potential alternatives, preparing and reviewing proposed project plans and developing preliminary cost estimates. Detailed engineering analyses are generally not required at this time. The level of engineering effort required for the following feasibility phase is identified and its associated costs estimated. Regional geologic and soils studies and field reconnaissances should be performed. In addition, an initial assessment of the hazardous and toxic waste (HTRW) potential of the study area shall be conducted during the reconnaissance phase as outlined in ER 1165-2-132. The reconnaissance is limited to 12 months.

2-3. Feasibility Study Phase

The feasibility study investigates and recommends solutions to water resource problems and, except for single-purpose inland navigation projects, are cost shared with a non-Federal sponsor. The feasibility study is the basis for Congressional authorization. Sufficient engineering and design should be performed to enable refinement of project features, prepare a baseline cost estimate, develop a design and construction schedule, and allow detailed design on the selected plan to begin immediately upon receipt of preconstruction engineering and design funds. Typical feasibility studies are completed in 3 to 4 years. General Design Memoranda (GDM) are not generally scheduled or planned. The geotechnical investigation program should assure that sufficient geologic and soils information are acquired and analyzed to verify the project plan, support site selection, selection of structures, assessment of foundation conditions, foundation design and selection of types of foundation treatment. Explorations should be in sufficient detail to support project design and the baseline cost estimate. Potential sources of concrete aggregate, earth and rock borrow, and slope protection material should be located and the investigations necessary to prove-out and develop these sources identified. If needed, further HTRW assessments are conducted during the feasibility study phase as outlined in ER 1165-2-132.

2-4. Preconstruction Engineering and Design Phase

The preconstruction engineering and design phase (PED) is an intensive effort which ends with the preparation of the plans and specifications (P&S) and the award of the first construction contract. PED costs are shared in the same percentage as the purpose of the project. Necessary design memoranda (DM) are prepared and P&S are prepared for the first contract. Geotechnical investigations should be project feature specific and should validate and refine designs and costs developed during the feasibility study. Final investigations in support of development of the test quarry and conduct of the test fill should be completed. If the test quarry and test fill programs are to be accomplished by hired labor, or as contract explorations, they may be accomplished during the PED. If they are to be accomplished by construction contract, P&S should be prepared. The PED phase generally requires about 2 years. HTRW activities, if any, during the PED phase shall follow the procedures outlined in ER 1165-2-132.

2-5. Construction Phase

Engineering effort during the construction phase includes final design efforts, preparation of remaining DM's and preparation of P&S for subsequent construction contracts, site visits, initiation of any foundation report, development of Operation and Maintenance (O&M) manuals and emergency action plans and preparation of as-built drawings. In multi-contract projects, test quarry and test fill development may be accomplished at the beginning of the construction phase. HTRW activities, if any, during construction, shall follow the procedures outlined in ER 1165-2-132.

Table 2-1
Sequence of Geotechnical Investigations with Project Development Phases

Civil Works Project Development Phases	Geotechnical Investigations
Reconnaissance Phase	Development of Regional Geology and Field Reconnaissance
Feasibility Phase	Site Selection and Initial Field Investigations
Preconstruction, Engineering, and Design Phase	Foundation and Design Investigations and Constructibility Review
Construction Phase	Quality Assurance and Post-Construction Documentation Activities
Operation and Maintenance Phase	Special Investigations as required

(Adapted from ER 1110-2-1150 and EM 1110-1-1804)

2-6. Operations Phase

Engineering activities during the operations phase generally consist of the participation in periodic inspections and design and P&S preparation for major repair and rehabilitation projects.

Chapter 3
Regional Investigations and Site Reconnaissance

3-1. General

Regional geologic and site reconnaissance investigations are made to develop the overall project geology and to scope early site investigations. The required investigation steps are shown in Figure 3-1. Detailed guidance on the conduct of these investigations is contained in EM 1110-1-1804. Additional guidance specific to determining the probable need for a test quarry, development of potential test quarry locations, and definition of necessary site investigations is provided in the following paragraphs.

3-2. Initial Regional Geology Studies

The overall regional geologic model resulting from inter-agency coordination, literature surveys, and map and remote sensing studies will assist in the decisions concerning the most efficient and economical project components and their tentative siting. As this project formulation proceeds, the potential need, or lack thereof, for produced rock materials will develop. During the coordination and information survey stages, information can be sought concerning existing sources of rock material in the region. On-line computer aided information retrieval services are readily accessible and can provide detailed reference lists. Information on regional and local geology, etc., relevant to site selection and design may be available from the U.S. Geological Survey. The U.S. Bureau of Reclamation maintains data on their project quarries as a function of broad rock genesis. Additional information on data sources is contained in EM 1110-1-1804. As part of the development of the geology of the region, special attention should be paid to the existence of regional stress fields in terms of how they may affect potential quarry excavations and produced rock products. In addition to determining groundwater conditions for normal project purposes, their effect on potential quarry excavations should be assessed.

3-3. Field Reconnaissance

Field reconnaissance should be made concurrent with, or immediately following the regional geologic studies. While the field reconnaissance stage does not include detailed studies such as geologic mapping, there are a number of observations that can be made that will assist in the decision to employ test quarry programs and in the probable quality of rock fill material that would be produced. Rock types, as noted from existing geologic maps, literature, and remote sensing studies can be confirmed. Tentative depths of overburden and weathered rock can be established. Outcrop observations can provide preliminary information on geologic structure and fracture frequency. Terrain conditions as they relate to tentatively selected required excavations can be determined. From the information obtained during the field reconnaissances, preliminary test quarry layouts can be developed, blasted rock gradations and relative amounts of rock waste can be predicted, follow-on investigations planned and program costs can be estimated.

3-4. Survey of Existing Excavations

As part of the field reconnaissances, or as a separate activity, known existing rock quarries and underground excavations, such as mines and tunnels should be visited and assessed. The USAEWES (1988) Technical Memorandum 6-370 provides information on, and test data from, quarries in the local area. Information can be obtained on lithology, structure, and fabric for the same or rock types similar to those at the tentative project locations. Information on produced rock gradations and amounts of rock waste can be obtained. Blasting patterns, types of explosives and blasting procedures can be assessed. Information on required processing and processing equipment (grizzlies, crushers, screens, etc.) can be obtained. When visiting quarry operations, check sheets should be prepared and filled out to assure that pertinent information is obtained. Items which should be included in such check sheets are shown in Table 3-1.

DEVELOPMENT OF REGIONAL GEOLOGY

DATA COLLECTION

INTERAGENCY COORDINATION AND COOPERATION

Sources of geologic, hydrologic and soils data; insight into geologic hazards and HTRW problems; seismicity; construction materials; prior regional experience.

SURVEY OF AVAILABLE INFORMATION

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

MAP STUDIES

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

REMOTE SENSING STUDIES

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

FIELD RECONNAISSANCES

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

DATA ANALYSIS

DISTRIBUTION OF ROCK TYPES

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

DISTRIBUTION OF SOIL TYPES

Equate geologic/soil 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; rock and soil 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 hydraulics 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 rock and soil sources delineated

Regional geologic and soils conditions established; preliminary assessments of seismicity and construction materials; tentative models of geologic conditions at potential sites developed; preliminary inputs to EIS and HTRW reports developed.

Figure 3-1. Schematic diagram of the development of regional geology (adapted from EM 1110-1-1804)

Table 3-1
Items for Inclusion in Quarry Inspection Check Sheets

Project and quarry	Blast hole drilling sizes and patterns	Rock size and gradation requirements
Dates of operation		
Purpose of quarry	Explosives used and powder factors	Volumes of rock produced
Rock type with lithologic descriptions	Hauling and processing equipment	Records of disputes between contractor and client
Rock structure and fabric	Relation of natural block sizes to rock comminution	Rock service records
Descriptions and costs of investigations	Amounts of rock waste	Remarks
Lab test data		

Chapter 4
Field Investigations

4-1. General

As previously shown in Table 2-1 for the feasibility phase and the preconstruction engineering and design phase of project development, geotechnical field investigations may be divided into two stages: Site Selection and Initial Field Investigations, and Foundation and Design Investigations. The need for this division depends on the planned size and complexity of the project. As a simple rule of thumb, if there is an envisioned need for test quarry and test fill operations, the two stages of field investigations are probably justified. Figures 4-1 and 4-2 show the required investigation steps for the two investigations stages. Guidance specific to the layout and conduct of the field investigations required to locate and design test quarry operations is provided in the following paragraphs.

4-2. Geologic Mapping

Surface geologic maps of potential test quarry sites should be prepared during the areal and site geotechnical mapping phase of the site selection investigations. The regional geologic maps, developed during the reconnaissance phase, commonly will have scales of 1:62,500 or larger. Depending on the size of the project, the areal (e.g. reservoir) geologic maps prepared during the current investigations phase may have scales of between 1:12,000 and 1:62,500. Structure site geologic maps would have scales of from 1:1,200 to 1:4,800. Potential test quarry sites should be mapped at scales comparable to larger scale site maps. The scales should be such that soil and rock type contacts can be shown, the location and shape of individual outcrop areas can be plotted, observed bedding and joint symbols can be plotted without cluttering the map, planned surface geophysical and core boring exploration plans can be shown, and planned excavation layouts can be shown. The outcrop mapping method is best for this type of work. An excellent reference for this type of mapping is Compton (1962). The geologic map produced and accompanying test data should include a complete lithologic classification description of the rock types present. In addition, the degree of weathering existing in the rocks at the site should be detailed.

4-3. Geophysical Investigations

Detailed guidance and information concerning the use of exploration geophysical methods and equipment are contained in EM 1110-1-1802. Of specific interest in quarry site explorations are: overburden depths, location and orientation of rock contacts, groundwater depths, seismic velocities, and rippability. Of the available surface geophysical exploration methods, seismic refraction, reflection profiling, and electrical resistivity are relatively economical and will provide the required information. Of the available borehole methods, up and downhole seismic, and electrical logging will provide the appropriate data. The spacing of surface seismic and electrical resistivity lines should be a function of the variability of top of rock elevations and rock-type distribution as inferred from the detailed geologic mapping.

4-4. Subsurface Explorations

The subsurface explorations stage can be carried out concurrently with or toward the end of the surface geophysical stage. Lagging behind the start of surface geophysics allows the results of the geophysical profiling to assist in the layout of the boreholes. Conversely, borehole information will assist in the interpretation of the geophysical data.

a. Core borings. For the purposes of exploring the sites of proposed rock excavations and test quarries, with rare exception, rock core borings are the most suitable drilling method. For most investigations in hard rock, "N" size diamond core borings which acquire a nominal 5.1 cm (2-in.) diameter core are satisfactory. For soft and/or highly fractured rocks, "H" size (nominal 7.6 cm (3-in.) diameter cores) or 10.2 cm to 14.0 cm (4 in. to 5.5 in.) diamond core borings may be necessary. As with the spacing of surface geophysics lines, the number and spacing of exploratory borings is a function of the anticipated rock variability. The borings should be arranged to facilitate the preparation of geologic cross sections with the borings at the ends of the anticipated cross sections outside the planned excavation limits; interpolation is much less risky than extrapolation. Borings should be located at the intersection of geophysical profiles to assist in correlation. Depending on the surface mapping results, it may be necessary to drill a number of angle holes to eliminate bias in borehole fracture surveys. Barring other

SITE SELECTION INVESTIGATIONS

DATA COLLECTION

AREAL AND SITE GEOTECHNICAL MAPPING

Prepare area and site maps for each candidate site; distribution of surface materials; outcrop locations; rock structure; springs; slope conditions; potential hazards; determine boring and geophysical survey locations.

GROUNDWATER DATA

Review data; compile water well and other piezometric data; determine needed additional data; start field collections

SURFACE GEOPHYSICAL SURVEYS

Subsurface material distribution at potential structure sites and quarry and borrow areas; water table depths; data on electrical and elastic material properties. If needed, start special surveys (e.g. to obtain dynamic properties or void detection)

SUBSURFACE EXPLORATIONS

Borings at potential structure and quarry and borrow areas; log soil and rock types, rock structure and drilling conditions; water pressure or pumping tests; camera or TV surveys; in hole geophysical surveys for correlation and, where needed, special properties.

MATERIAL TESTING

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

DATA ANALYSIS

AREAL CONDITIONS

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

SITE CONDITIONS

Compile detailed geology maps 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; assess test results, discuss soil and rock engineering properties.

GROUNDWATER CONDITIONS

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

EARTHQUAKE ANALYSES

Determine design earthquakes for each site; perform preliminary dynamic analyses; evaluate foundation areas for liquefaction and potential fault movement.

CONSTRUCTION MATERIALS

Locate and describe proposed quarry and borrow sites; prepare detailed geologic maps and sections for each; determine available volummes of material and depths of burden; describe properties; assess commercial sources.

MINERAL AND OTHER RESOURCES

Determine location and extent of resources which may be impacted by project.

Project areal and site geotechnical conditions developed and defined to extent necessary to select most effective and economical site, develop reliable cost estimates and to initiate detailed design studies. Environmental and HTRW conditions are defined and input to impact statements completed.

Figure 4-1. Schematic diagram of initial and site-selection investigations (adapted from EM 1110-1-1804)

considerations, or purposes for the borings, the depths of the core borings should be 1.25 to 1.33 times the depth from the ground surface to the bottom of the planned excavation.

DESIGN INVESTIGATIONS

DATA COLLECTION

ENVIRONMENTAL/GROUNDWATER

Continue needed ground water data collection; observation well readings, pump tests, etc.; collect geotechnical data needed to update environmental assessments.

SUBSURFACE EXPLORATIONS

Expand coverage at selected structure sites, excavations, material sources and relocations; log soil and rock types, structure and drilling conditions.

BOREHOLE PHOTOGRAPHY/TV

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

BOREHOLE GEOPHYSICS

Expand coverage with non-core borings; obtain in situ properties and stratigraphic correlation.

WATER PRESSURE AND/OR PUMPING TESTS

Obtain permeabilities; monitor water levels.

MATERIAL TESTING

Complete classification and index testing; perform engineering properties tests; continue and complete special testing started in earlier stages.

EXPLORATORY EXCAVATIONS AND CONSTRUCTIONS

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

INSTRUMENTATION

Install and initiate readings on foundation instrumentation (e.g. piezometer, slope indicators) to develop baseline conditions.

DATA ANALYSIS

GROUND WATER CONDITIONS/ASSESSMENT

Continue analyses started in earlier program; finalize statement of project impact on ground water.

PROJECT SITE CONDITIONS

Update site geologic maps, geologic sections, rock and soils 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 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 events occurring; produce baseline plots for construction and post construction conditions.

RELOCATIONS

Develop pertinent data for each relocations 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 and HTRW assessments.

Figure 4-2. Schematic diagram for design investigations (adapted from EM 1110-1-1804)

b. Drilling, inspection, and sampling. General guidance for drilling, inspection, and core logging is contained in EM 1110-1-1804. The U.S. Bureau of Reclamation Engineering Geology Field Manual (1989) and Murphy (1985) contain comprehensive information on both core and soils logging and on rock mass descriptions. All of the rock descriptors recommended in the cited references are important to test quarry applications. Of particular importance are weathering, presence of clay or gouge seams, and the in situ gradation. Given a rock material of certain hardness and density, these types of descriptors will form the basis for estimates of waste and the need for and design of rock processing equipment. The degree of weathering should be described according to some standard such as that contained in EM 1110-1-1804. In situ fracture frequency and orientation can provide the information required to calculate in situ rock block-size distribution. In addition, correlations have been developed between rock-quality designation (RQD) and mean fracture frequency. The general use of RQD is treated in ETL 1110-1-145. When logging rock core, in addition to logging core loss and RQD, the geologist/inspector should note the depth and angle (with respect to borehole axis) of every identifiable fracture and note its genesis (joint, bedding plane, drill break, etc.). As a practical matter, when the fracture spacing is less than 3.0 cm (0.1 ft), that interval of core may be logged as "broken." This data will allow the prediction of in situ rock block-size distributions. In addition, it will be of value for the geologist/inspector to note those parameters which are used in currently popular rock mass classification systems such as "RMR" or "Q" systems (ASTM 1988). The use of rock mass classification systems is discussed further in Chapters 6 and 7. Information and guidance on sampling and sample preservation of soils and rock core are contained in EM 1110-1-1906, and ASTM Designations: D 4220 (ASTM 1994a) and D 5079 (ASTM 1994b). Sample preservation for moisture content is generally not necessary in hard, crystalline rocks. Such rocks generally exhibit intact rock material porosities less than one percent and moisture content is inconsequential to densities and other parameters. In softer sedimentary or chemical precipitate rocks, the porosities are sufficiently great that moisture content does affect bulk densities and other parameters. In these rocks, the geologist/inspector should select and preserve representative samples for moisture content determinations.

c. Borehole examination and in-hole testing. Borehole examination and in-hole testing includes borehole photography, TV and sonic imaging, borehole geophysics, hydraulic or water pressure testing, water table measurements, and in-hole deformation or jacking tests. Guidance and information on these methods are contained in EM 1110-1-1802, EM 1110-1-1804, the Corps of Engineers Rock Testing Handbook (USAEWES 1993), and the U.S. Bureau of Reclamation Engineering Geology Field Manual (1989). The borehole geophysical methods most pertinent to test quarry explorations have been described in paragraph 4-3. Tests to determine in situ stresses would be warranted only if there were indications of abnormally high horizontal stresses which might affect excavation slope stability and markedly affect rock breakage. For test quarry explorations, water pressure testing normally would not be necessary. Water table measurements are necessary for excavation slope and dewatering design purposes. For test quarry explorations, borehole photography, TV, and sonic imaging are the most important measurements. Because they provide detailed information on rock structure, these measurements will provide input to design analyses of probable rock waste, in situ rock block-size distribution, trial blast patterns and loading, and rock excavation slope stability calculations and slope design.

Chapter 5
Laboratory Testing

5-1. General

As shown in Figures 4-1 and 4-2, material testing is part of both the Site Selection and the Design Investigations. In terms of timing or scheduling, laboratory material testing would be performed as close to concurrent with the subsurface exploration stages as possible. EM 1110-1-1804 provides guidance and information on types of soil and rock tests for various design applications. EM 1110-2-1906, the Corps of Engineers Rock Testing Handbook (USAEWES 1993), and ASTM (1994a through 1994d) all provide detailed information on the procedures for conducting tests on soil and rock materials. Rock and soils tests are informally divided into two categories: index tests to identify and classify the materials, and engineering properties tests to supply parameters for design analyses. The following paragraphs discuss the applicability of selected tests for test quarry design.

5-2. Petrographic Examination

A detailed discussion of recommended practice for petrographic examination of rock cores is contained in the Corps of Engineers Rock Testing Handbook (USAEWES 1993). Petrographic examinations are conducted to describe, classify, and determine the relative amounts of the sample constituents, identify the sample lithology, to determine the sample fabric, and to detect evidence of rock alteration. The identification of rock constituents and determination of fabric and micro-structural features assist in the recognition of properties that may influence the engineering behavior of the rock. Complete petrographic examination may require the use of such procedures as light microscopy, x-ray diffraction, differential thermal analysis, and infrared spectroscopy. The selection of specific procedures should be made by an experienced petrographer in consultation with geologists and engineers responsible for the design and execution of the test quarry program.

5-3. Weight/Volume Properties

The weight/volume and pore properties of a rock material include specific gravity of solids, porosity and absorption, apparent and bulk specific gravity, moisture content, and degree of saturation. These properties are directly important to predictions of "swell" or "bulking" and serve as index tests relating rock strength and deformability. As a general rule, for test quarry design, bulk specific gravity and absorption are the minimum weight/volume tests that need to be performed. If a quarry is intended to produce dimension or derrick stone, absorption and adsorption may provide an indication of the rock's long-term resistance to freeze-thaw and slaking. The relationships between bulk specific gravity (G_m), absorption (A_B), and porosity of the rock particles (n_r) are given below. The porosity here refers to the permeable voids associated with individual rock particles and not to the porosity of a compacted mass of such rocks.

$$G_m = \frac{A}{B - C} \tag{5-1}$$

$$A_B = \frac{B - A}{A} \tag{5-2}$$

$$n_r = A_B \times G_m \tag{5-3}$$

where

A = weight of oven-dry specimen

B = weight of saturated surface-dry specimen

C = weight of saturated surface-dry specimen in water

5-4. Strength Tests

Unconfined compressive strength is a well known index test relating intact rock strength and deformability. Further, it can be used with rock mass quality descriptors to infer rock mass strength parameters (Hoek and Bray 1981). Unless there are specific requirements relating to rock slope design problems, there is no need to perform tests such as the triaxial shear or direct shear tests. An inexpensive and rapid test which correlates to unconfined compressive strength is the point load test (Bieniawski 1975). This test is growing in popularity and can be performed either in the laboratory or the field.

5-5. Rock Durability Tests

Laboratory durability tests are divided into those that simulate accelerated weathering and those that measure physical properties. Accelerated weathering tests usually include wet and dry (Designation D 5313; ASTM 1994a), freeze and thaw (Designation D 5312; ASTM 1994a), sodium sulphate soundness and magnesium sulphate soundness (Designations D 5240 and C 88; ASTM 1994a and 1994b, respectively). Physical property tests include absorption (Designation C 127; ASTM 1994b), Los Angeles Abrasion (Designation C 535; ASTM 1994b), and slake durability (Designation D 4644; ASTM 1994c).

Chapter 6
Location and Design of Test Quarries

6-1. General

The final location, physical size, and design of a test quarry is made using the information obtained during the reconnaissance, site selection, and initial and design investigations. The development of the test quarry program and the test quarry design is an iterative process. Preliminary requirements for and locations of test quarries are developed during the reconnaissance phase of project development and refined sufficiently during the feasibility phase to provide accurate data for baseline cost estimates and for proceeding to detailed design during the preconstruction engineering design phase. The process of locating and designing the project test quarry, or test quarries, follows a logical sequence as described in the following paragraphs.

6-2. Evaluation of Project Rock Production Requirements

Concurrent with the investigations required to locate and design a test quarry are those required to determine embankment design, including zoning and slope protection requirements. The need for rock-fill zones in an embankment arises from the overall analyses of the amounts of different types of fill materials available and the results of cost studies of various embankment cross sections and alignments. The decision to design and construct a rockfill embankment is made based on design safety considerations and on analyzing the comparative costs among rock, earth-rock, and earth embankments and concrete structures. Guidelines on the procedures for selecting the safest and most economical design are contained in EM 1110-2-2300. As the embankment design develops, volumes for different qualities and gradations of rockfill are determined. These are compared with the probable amounts of rock of those qualities and gradations that design investigations indicate are available in required excavations or in separate excavations specifically planned to supply rock material. This process is iterated until the most economical balance between excavation and fill requirements is obtained which will produce a safe embankment. The supply of rock reserves available for construction of the dam must be accurately estimated, taking into account bulking and/or shrinkage factors. These quantity estimates can be greatly improved if bulking and shrinkage factors are determined during test quarry and test fill development.

6-3. Evaluation of Potential Test Quarry Sites

At this stage in the design process, required excavation and/or stand-alone quarry sites have been explored as potential sources of construction materials. It remains to evaluate these sites and decide upon one or more test quarry locations which will provide data that are most representative of the conditions to be encountered in the project excavation(s). The quarry or quarries should be sited so that all large-volume rock types to be used in construction and all associated rock conditions will be assessed and tested. If the amount of a particular rock type will be relatively small and failure to assess it will result in errors of minor technical and economic consequences during construction, the time and cost of developing a test quarry only to assess it may not be justified.

a. Rock type distribution considerations. The test quarry, or quarries, should sample the same rock types, in roughly the same proportionate quantities, that will be provided from the actual project excavation(s). A project may be located in one rock or several depending on the areal geologic sequence (sedimentary, igneous, metamorphic). The degree of heterogeneity will control the number and location of test quarries. In a relatively homogeneous igneous or metamorphic crystalline rock, one test quarry of sufficient size to sample the unweathered rock may suffice. In a bedded sedimentary sequence, a large spillway excavation may be planned to cut across several rock types. Ideally, the test quarry should be of sufficient size that it will sample this heterogeneity and supply adequate materials for test fills. However, monies available at this stage may not allow a test quarry of that size. A number of smaller test quarries may provide a representative blend of materials for test fills and provide representative information on rock gradations, waste and slope design. However, great care must be used in modeling of the rock conditions to be produced from one large excavation with a number of smaller excavations. As will be pointed out in paragraph 7-2*b*, there are potential problems involved in not siting the test quarry within the area of the intended project borrow excavation.

b. Geologic structure and fabric considerations. Test quarries should not be located so that they include gross or meso-scale geologic structural features such as faults and solution cavities. Macro-scale geologic structure, such as joints and bedding planes, affects both the gradation of the blasted rock mass and the stability of the quarry slopes. The regional residual stress field will have an effect on quarry slope stability and on rock fragmentation. The effect of the geologic structure on the design of the quarry slopes will be discussed below in paragraph 6-3*d* and its effect on the blasted rock mass gradation will be discussed in paragraph 6-3*c*. Geologic fabric, or arrangement of the rock's mineral constituents, affects both the ease with which comminution occurs under the dynamic loads of explosives and the shape of the blasted rock fragments. The test quarry, or quarries, should be sized and located so that all the variations of geologic structure which will be encountered in the project quarry excavations will be sampled. Generally, an adequate sampling of rock fabric is obtained if the test quarry, or quarries, adequately sample all the rock types to be encountered in the project construction situation.

c. Rock quality and gradation considerations. As with rock type, geologic structural and fabric considerations, the number and size of test quarries should be selected so that the variations in rock quality over the planned construction quarry excavations are sampled. If, as recommended in paragraph 4-4*b*, sufficient data were collected during subsurface investigations to employ the use of a rock-mass classification system, the rock mass in the required excavations can be divided into zones of different rock mass qualities and that zoning can assist in the location of the test quarries. The in situ rock block-size distribution will have a great deal of influence on the gradation of the blasted rock. The degree of variation of in situ block-size distribution can be established from the logs of exploration core borings. There are two ways to assess this degree of variation. Mean block-size distribution for pre-selected lengths of each bore hole can be estimated from *RQD* using the following relationship (Brady and Brown 1985).

$$RQD = 100\ e^{-0.1\lambda}\ (0.1\lambda + 1) \tag{6-4}$$

where e is the exponential and λ is the mean number of discontinuities per meter. Figure 6-1 shows the relationship between *RQD* and mean discontinuity frequency. A more site-specific and accurate method of estimating the in situ block-size distribution is to make cumulative fracture frequency curves from the fracture counts on the boring logs and/or from borehole photography logs. This will allow the division of the rock mass by the mean fracture spacing and variance in a manner similar to zoning the rock mass according to rock mass quality.

d. Rock slope design considerations. Because the test quarries will provide the opportunity to test the project excavation slope designs, the test quarry excavation(s) should be configured to duplicate project slope inclinations and orientations. As part of the test quarry location and sizing analyses, slope stability evaluations should be employed for trial quarry configurations. Preliminary evaluations of slope stability can be performed with graphical analyses using stereographic or equal-area projections. An example of such an evaluation is shown in Figure 6-2. If preliminary evaluations indicate potential instabilities, more detailed planar and wedge stability analyses should be performed. An excellent series of discussions on rock slope stability analyses is presented by Hoek and Bray (1981). There should be sufficient slope area to test all potential presplit configurations.

6-4. Test Quarry Layouts

Test quarries should be located, if feasible, within the perimeter of the area to be used as the primary source of rock for project construction. Reasons for this will be discussed in paragraph 7-2*b*. As stated in paragraph 6-3, the quarry, or quarries, should be located so that all major rock types and rock conditions can be tested and evaluated. It is presumed that, before final selection of the test quarry site(s), sufficient core borings will have been drilled in each potential quarry location to determine if the desired rock type and rock conditions will be encountered in the selected test quarry(ies). The layout of each quarry must take into consideration the slope of the terrain, the depth of overburden and saprolite, the configuration of the objective strata, and accessibility to the test fill site. Cost of the test quarry is always a consideration; the location and layout must achieve reasonable economy. Figures 6-3 through 6-6 are examples of single-test and multiple-test quarry layouts, respectively.

a. Stripping requirements. It is necessary to strip all of the overburden and saprolite and haul it to a disposal site prior to initiation of rock excavation in the test quarry. This is important because the rock fill produced in the test quarry should not be contaminated by the overlying materials. It is advisable to create a berm or bench on the order of 3 to 7 m (10 to 20 ft) wide between the base of the slope through overburden and the beginning of the first rock excavation slope. This should be done to control surface drainage and raveling of overburden into the quarry during the continuing excavation.

b. Size and alignment. The size of the test quarry is dictated by a number of different factors. Depth to the target rock formation, quantity of material required for test fills, geologic structure and side slopes, variations in rock types and rock quality, and the number of test blasts needed are all factors which must be considered in

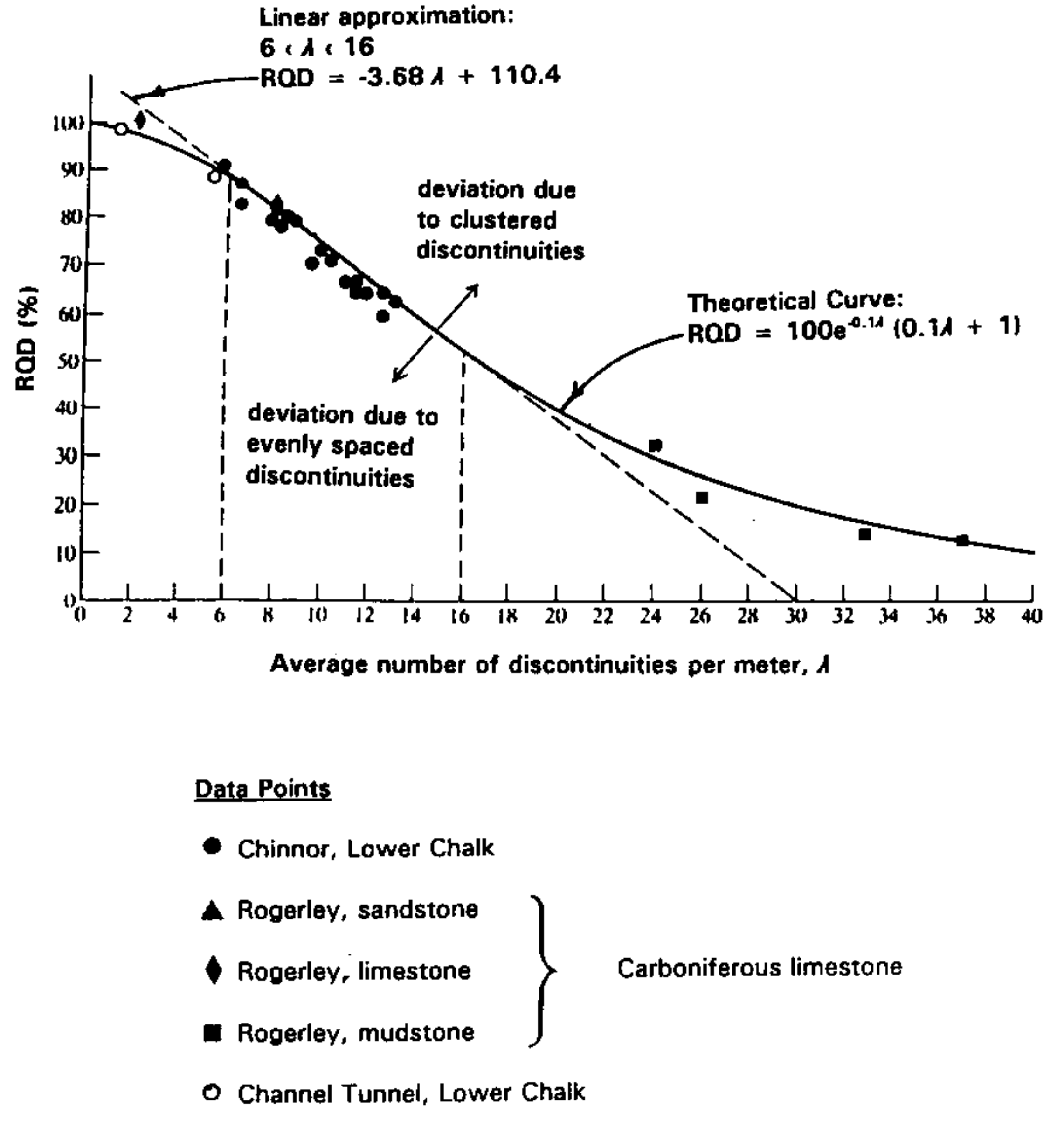


Figure 6-1. Relationship between *RQD* and mean discontinuity frequency (after Brady and Brown 1985)

designing the dimensions of the test quarry(ies). It is important to plan the size of the excavation larger than the minimum required in case it becomes necessary to excavate the quarry deeper than the design depth. Extending an exact-sized quarry to greater depth would require re-excavating the slopes in order to maintain their stability. This may become prohibitively expensive. The alignment of the excavation is affected by some of the factors that affect its size but terrain configuration frequently controls the alignment. An example of terrain-controlled alignment is shown in Figures 6-3 through 6-5.

c. Slope and bench designs. Slope design should be based upon rock slope stability analyses employing rock fracture orientations developed from the geologic investigations and rock shear strengths developed from the results of laboratory testing. One purpose of the test quarry is to field test the slope design. For this reason,

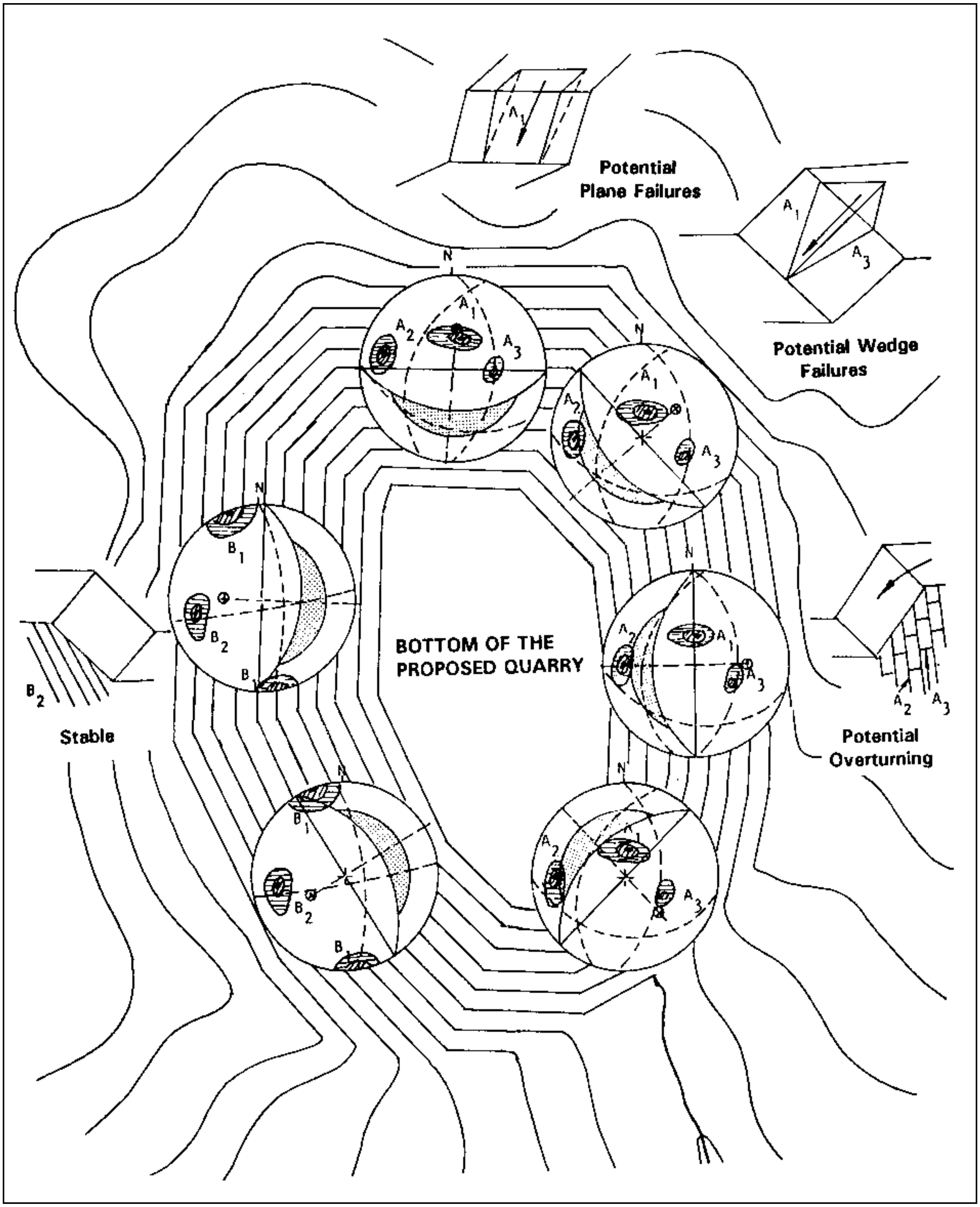


Figure 6-2. Example of a graphical slope stability evaluation of a proposed excavation (after Hoek and Bray 1981)

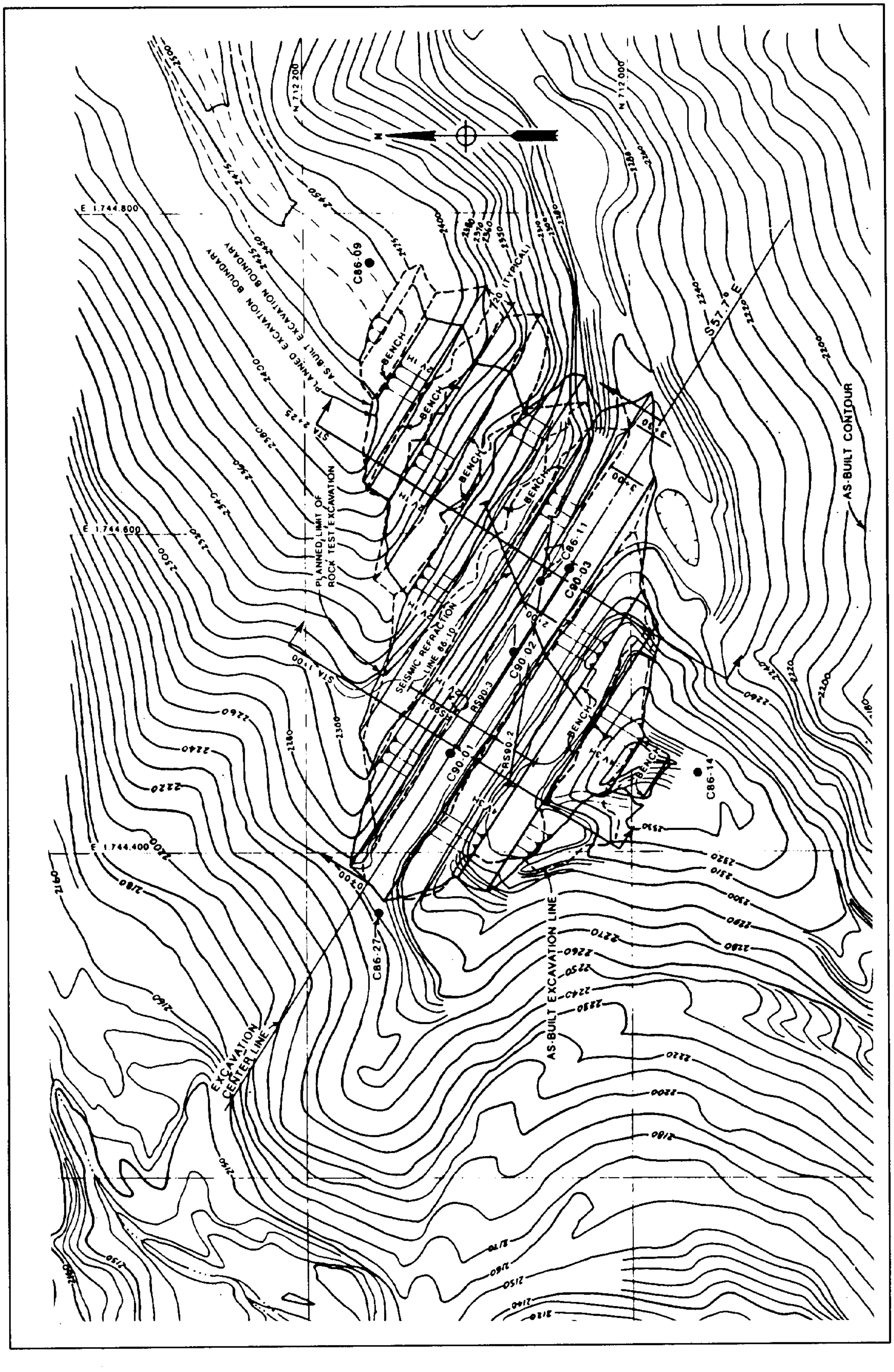


Figure 6-3. Example of a single test quarry layout showing bench and slope configurations, Seven Oaks Dam (after U.S. Army Engineer District, Los Angeles 1992)

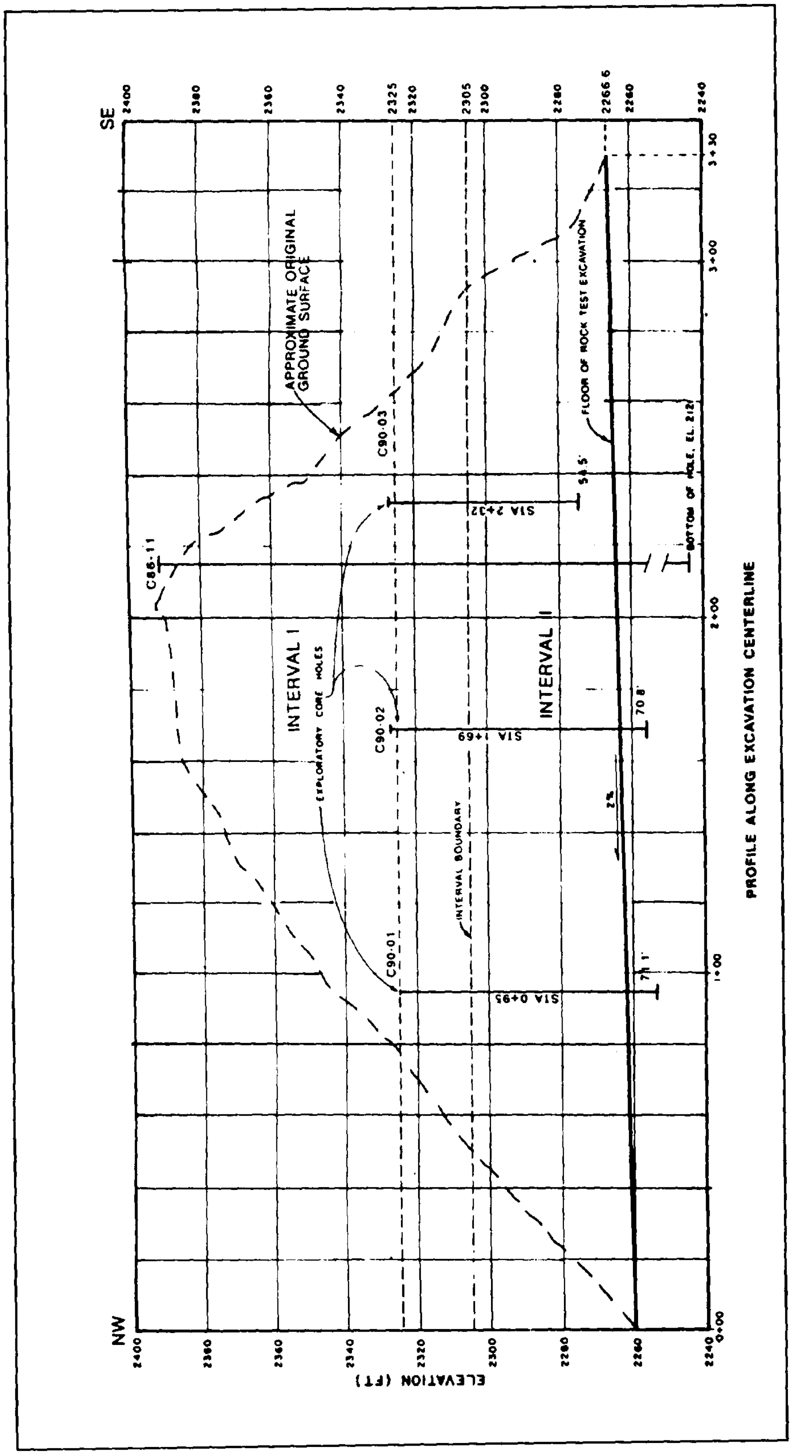


Figure 6-4. Profile along the excavation centerline of Figure 6-3

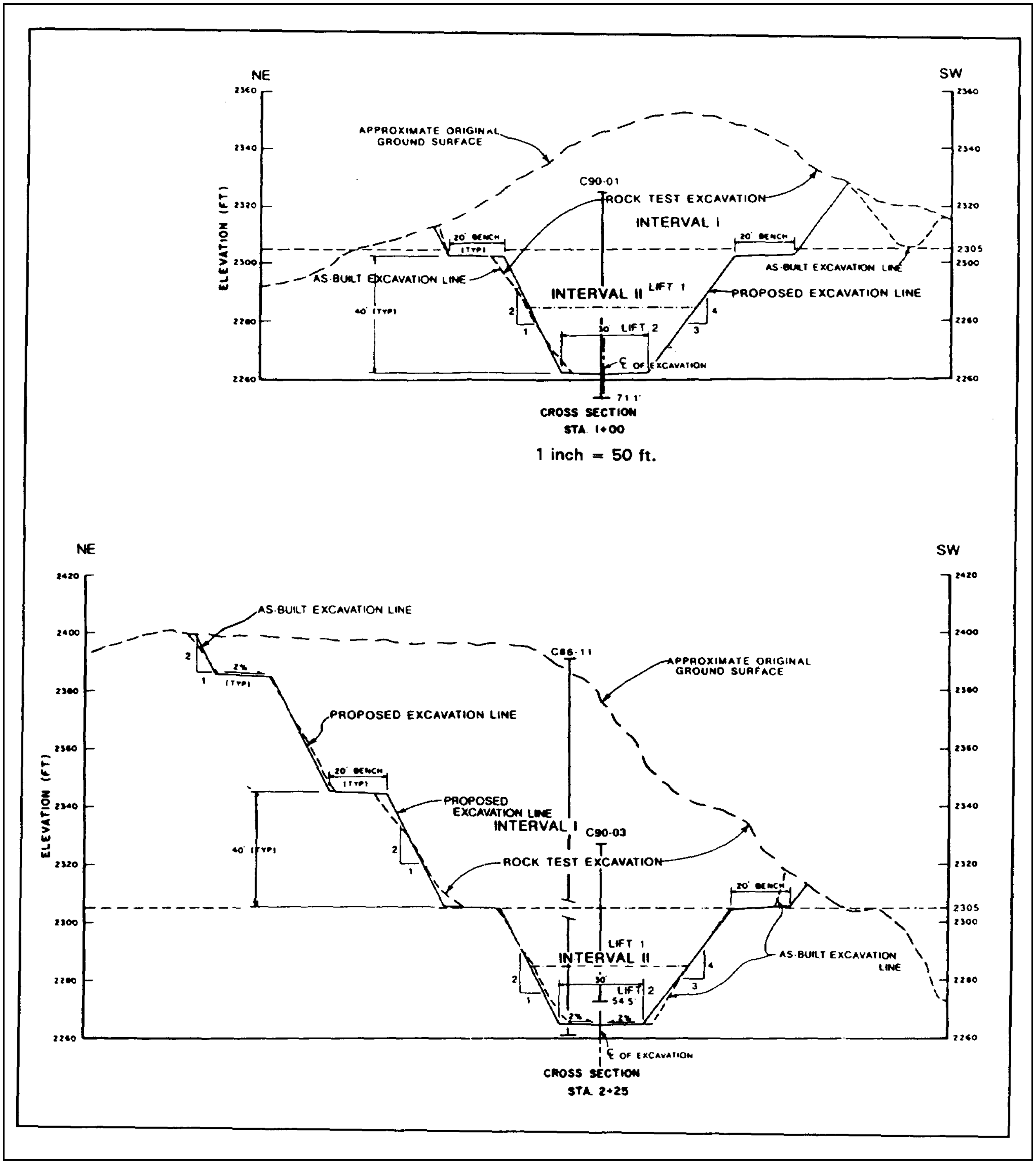


Figure 6-5. Additional sectional views of single quarry shown in Figure 6-3

several variations of the design should be tested in the quarry to prove and optimize the design. Bench design is based upon the overall slope stability analysis and upon the practicalities of excavation. The benches have the effect of flattening the overall slope and improving stability. They also provide added safety by catching some of the falling rock before it reaches the quarry floor. The benches can be sloped to control surface drainage and to provide haul road access to the quarry floor. Examples of slope and bench configurations are shown in Figures 6-3 through 6-5. Quarry bench height designs should be

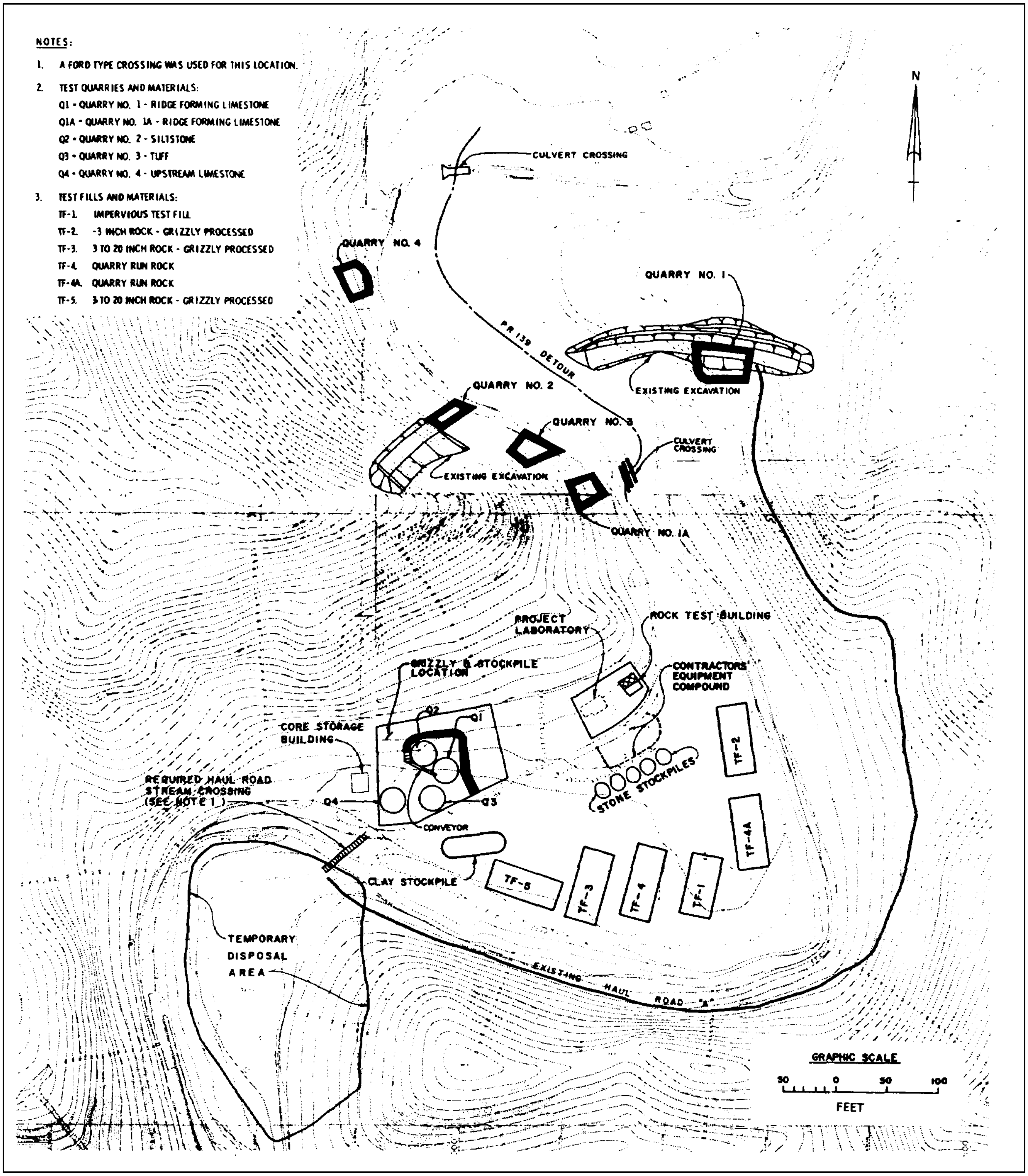


Figure 6-6. Example of a multiple test quarry layout where samples from several different rock strata are required for testing (after U.S. Army Engineer District, Jacksonville 1983)

based on anticipated excavation and hauling equipment and safety. Control of produced rock gradation is more a function of explosive type, quantity per hole, blast-hole spacing, decking of the charge, and burden than bench height. Where practicable, setting quarry benches coincident with slope berms will be efficient from a constructibility standpoint.

d. Presplitting patterns. The presplitting patterns developed during the design phase should be tested in the test quarry excavation. Variables in the design include hole spacing, hole size, stemming subdrilling, inclination, loading configuration, and charge weights. Hole spacing normally ranges from 46 to 91 cm (18 to 36 in.). The quality of the presplit slope normally decreases as the hole spacing increases, with 91 cm (36 in.) being about the maximum that will produce a satisfactory slope. It is important to maximize suitable spacing because this will reduce the number of presplit holes required and thereby reduce drilling costs. Good drilling alignment is very important to a satisfactory presplit slope cut. Alignment requires great care, particularly when drilling from rough or irregular surfaces. The techniques employed by the driller also affect the resulting alignment. It is important to specify great care in maintenance of alignment in the test quarry contract. It is also important to optimize the buffer zone between the presplit slope and the production blast lifts. Too large a buffer zone will keep the production blasts from pulling completely to the presplit slope and may result in incompletely broken rock. Too small a buffer zone will result in damage to the slope by the production blast. Variations of the combination of the above variables should be tested to determine which will work best under individual slope conditions. The basic designs should be furnished to the field with instructions that it will be modified as testing progresses and more is learned about the behavior of the rock mass. EM 1110-2-3800 provides detailed guidance on presplit design.

e. Production blasting patterns. There are numerous variables involved with blasting patterns which affect the particle size and gradation of the blasted rock pile. These variables and combinations thereof need to be investigated during the test quarry development to determine which combinations provide the most desirable rock fragmentation and gradation. Those variables that should be tested include: blast-hole diameter, hole spacing, powder factor, subdrilling depth, stemming type and length, type of explosive, loading configurations, decking, bench heights, firing delay patterns, and location of the free face (burden). It must be recognized that the characteristics of the rock mass impose limitations on the size of the produced particles. For instance, if rock joints occur on a repeating frequency of 30 cm (1 ft), it will not be possible to obtain significant quantities of rock with intermediate dimensions exceeding 30 cm (1 ft), no matter how the blasting pattern is designed. In other words, do not attempt a blast design to create fragmentation which is impractical to achieve. It is possible to achieve a gradation finer than the in situ gradation but not coarser. With this limitation understood, variations in the combinations of variables should be tested to develop those combinations which provide the most satisfactory rock mass fragmentation and gradation. The test quarry design should provide those patterns to be tested. The contract should provide for variations as more is learned from the initial tests. Figures 6-7 and 6-8 show examples of variations in test blasting patterns used to develop optimum patterns. EM 1110-2-3800 provides details on blast pattern design.

6-5. Gradation Measurements

There are no established standards or procedures specifically directed at making gradation determinations for blasted rock to be used in compacted rock fills. The new ASTM Designation D 5519-93 (ASTM 1994d) has become available (but not in time to be included in ASTM 1994a) for making gradation determinations for riprap and may be considered applicable. A complete discussion of gradation testing including ASTM 1994d is provided in Part II: Test Fills. The procedures used at the Corps of Engineers Carter’s, Cerrillos, and Seven Oaks dam projects and described in the following paragraphs represent the typical sorts of past practices relative to obtaining gradations for rock materials upon which the ASTM standard.for riprap was based .

a. Carter’s Dam. The gradation measurement procedure was to first carefully select a large representative sample from the blasted rock pile. The rock was then processed by hand over a series of inclined screens that separated the rock fragments into fractions of over 2.5 cm (1 in.), 7.6 cm (3 in.), 15.2 cm (6 in.), and 20.3 cm (8 in.). The minus 2.5-cm (1-in.) fraction was then processed with a Gilson® shaker using a normal nest of U.S. Standard Sieves (EM 1110-2-1906). The fragments from that fraction of the sample which were larger than 20.3 cm (8 in.) were individually passed through 30.5-cm (12-in.), 40.6-cm (16- in.), and 61-cm (24- in.) squares in order to determine the percent passing each of those sizes. It is necessary to obtain progressively larger representative samples for testing as the maximum particle size increases in order for the test results to be a satisfactory representation (estimation) of the blasted rock gradation. Figure 6-9 shows the configuration of the rock

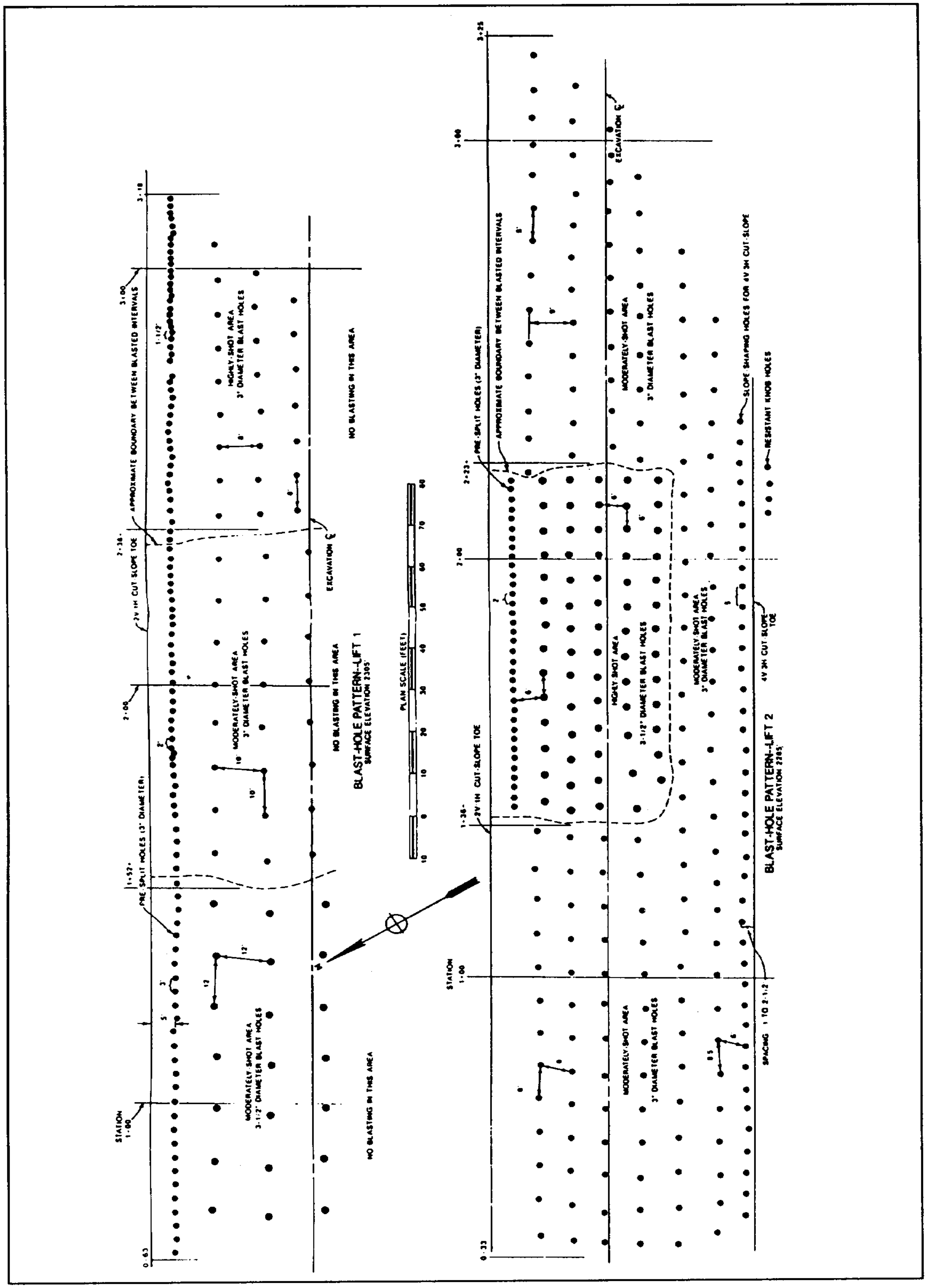


Figure 6-7. Example of variations in test blast patterns designed to develop the optimum production blast patterns (after U.S. Army Engineer District, Los Angeles 1992)

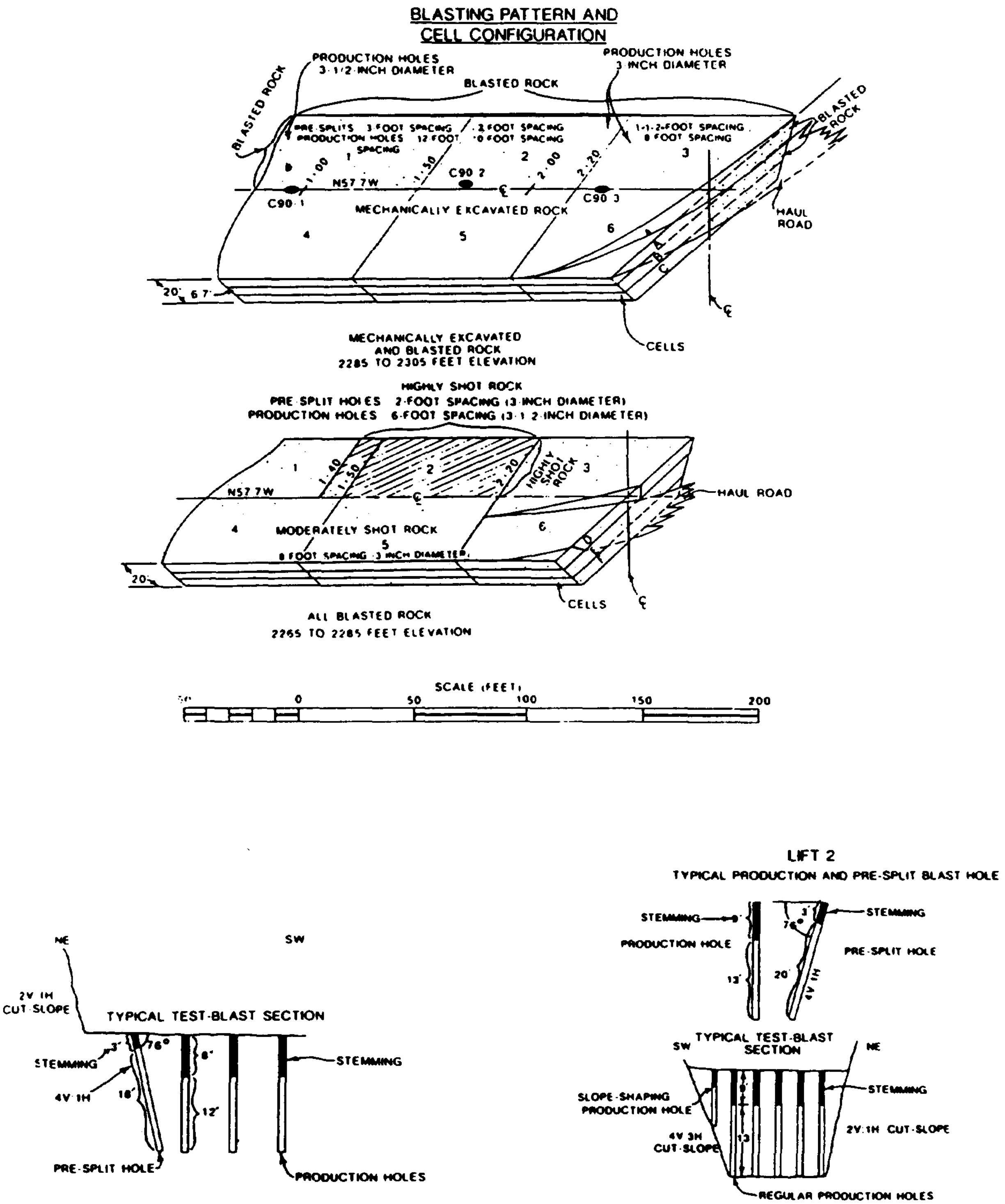


Figure 6-8. Additional information relative to Figure 6-7

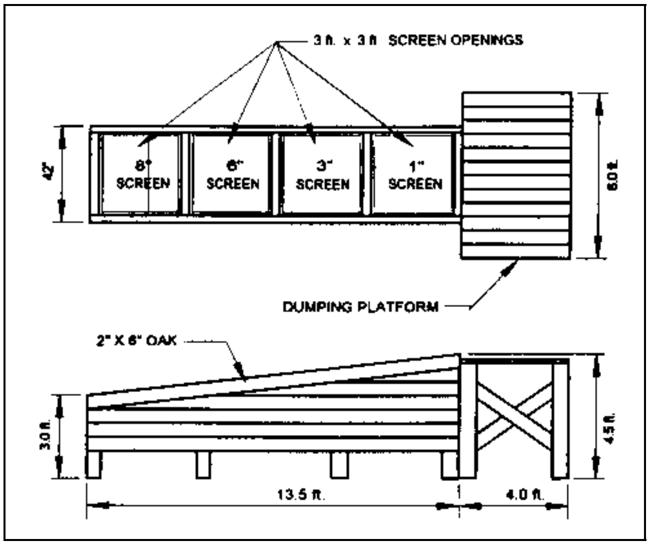


Figure 6-9. Example configuration of a rock gradation screening platform

gradation measurement platform used at Carter's Dam. The above information was obtained verbally from Mr. C. Colwell of the South Atlantic Division Laboratory (1993).

b. Cerrillos Dam. The gradation measurement procedure at Cerrillos Dam began with selection of a large sample weighing about 13.6 metric tons (30,000 lb). This sample was then split by the quartering method to obtain a sample weighing about 2.7 megagrams or metric tons (6,000 lb). The 2.7-metric ton (6,000-lb) sample was processed by hand over 15.2-cm (6-in.), 20.3-cm (8-in.), 22.9-cm (9-in.), 30.5-cm (12-in.), and 61-cm (24-in.) screens. The fraction passing the 15.2-cm (6-in.) screen was processed through a nest of screens using the Gilson® shaker. The gradation was based on the percent passing each screen size. This information was obtained verbally from Mr. P. Davila, U.S. Army Engineer Jacksonville District, Ponce (Puerto Rico) Resident Office (1993).

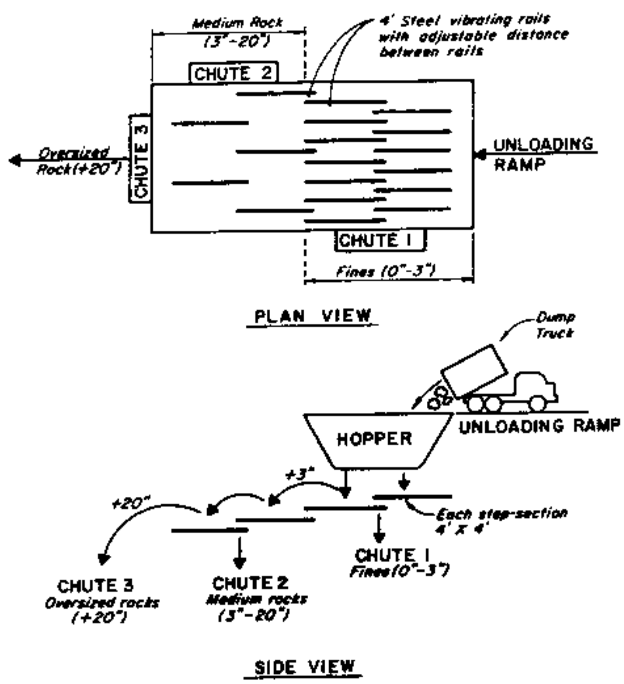
c. Seven Oaks Dam. Samples weighing approximately 4.5 metric tons (10,000 lb) were obtained and dumped on large sheets of plastic. These materials were sorted manually in the field using 7.6-cm (3-in.) opening Tyler screen and 15.2-cm (6-in.), 22.9-cm (9-in.), 30.5-cm (12-in.), and 45.7-cm (18-in.) sizing rings. The materials passing through the screen and sizing rings were placed in 2.1-cu m (55-gal) drums and weighed in the field on a platform scale. Individual rock fragments larger than 45.7 cm (18 in.) were measured in three diametrical directions and the weights estimated based on previously developed correlation charts. One drum of the minus 7.6-cm (3-in.) material from each sample was taken to the project laboratory for sieving and classification testing. This description was taken nearly verbatim from the U.S. Army Engineer District Los Angeles District Feature Design Memorandum (1992).

6-6. Deterioration and Incipient Fracture Examination

Some rock formations tend to deteriorate after excavation due to physical and/or chemical processes. This can have a very degrading effect on the rock products manufactured for various zones in a rock-fill dam and should be carefully evaluated during test-quarry and test-fill construction. Some conditions which lead to this type of deterioration are incipient fractures, bedding planes, abnormally high residual stresses, and chemically and/or physically unstable strata such as shale and volcanic ash or tuff. Some of this deterioration may occur in stock piles while some may occur due to the mechanical actions of loading, hauling, placement, and compaction into the fill. It is important to identify and assess degradation during the test-quarry and test-fill operation so that it can be dealt with during final design and construction. There are several approaches to determining whether or not this is a problem. Perhaps the simplest is to expose samples of rock core and blasted rock to the environment for a defined period of time and measure either changes in specimen size or weight loss. No changes would be an indication that degradation by chemical effects or weathering is not likely to occur in the rock fill. If changes do occur, then more sophisticated tests are needed to evaluate the magnitude of the problem. Petrographic analyses have provided an indication of breakdown due to incipient fracturing. Visual observations of individual blasted rock fragments are useful in determining the presence of incipient fractures or weak bedding planes. If there is an indication of either chemical or physical breakdown, it is desirable to obtain gradations of the blasted rock mass in the test quarry, then subsequently in the stock pile and ultimately in the test fills. These successive gradations will provide information on the degree of degradation which occurs. In some cases, it may be necessary to test repetitively in a stock pile to duplicate the times that a contractor is likely to stockpile materials. It is important to note that the mechanical action of repeatedly testing the same sample over a period of time may itself be a factor in any observed breakdown. This is discussed further in paragraph 7-6*b*. The blasting process often enlarges and expands incipient fractures and planes of weakness in intact rock blocks. This process will lead to degradation of the stone during project operation. The identification of blast damage is very important. Both District and Division Laboratory geologic personnel should be involved in the evaluation of blast damage.

6-7. Rock Processing

Rock processing is frequently called for in the design of an earth-rockfill dam. This is particularly true for the manufacture of filter materials and materials to be placed in zones adjacent to filters. Where processing is anticipated, it is important to process the rock being produced in the test quarry for the test fills. The decision to process for the project situation should be carefully conceived and evaluated because rock processing, both in the test program and in the project construction, is very expensive. In other words, the fewer the zones of the dam that require processing, the less expensive the dam construction will be. The test fills should be constructed from rock materials that have the same characteristics as the project material is expected to have. In order to obtain this, some processing is likely to be required between the test quarry and the test fills. This may involve processing over a grizzly as diagrammed in Figure 6-10 or may require a portable crushing and screening plant to be brought to the site. Paragraph 7-7 provides further discussion of processing.



FLOW DIAGRAM OF GRIZZLY OPERATION. MATERIAL IS DUMPED FROM RAMP INTO HOPPER. FINES ARE REMOVED THROUGH CLOSE SPACED RAILS INTO CHUTE 1 AND ALONG CONVEYOR BELT TO STOCKPILE. MEDIUM ROCKS ARE REMOVED BY NEXT SERIES OF RAILS AND PILE IS FORMED BELOW CHUTE 2. OVERSIZED ROCKS OVERRIDE BOTH SERIES OF RAILS AND FORM A ROCK PILE BELOW CHUTE 3.

Figure 6-10. Flow diagram of a grizzly operation

Chapter 7
Test Quarry Operations

7-1. Supervision

A major purpose of a test quarry is to determine how rock characteristics and excavation variables affect the rock material produced and how they affect the side slopes and bottom of the excavation. The technical aspects of the test quarry operation are normally best supervised by a geologist experienced in rock excavation methods and procedures. This person, the Technical Test Quarry Supervisor (TTQS) should have sufficient staff to allow complete oversight of the contractor's operations as the work progresses. This work differs from a normal construction contract operation because it is an exploration and testing program with the objective of developing data and procedures to be subsequently incorporated into project design and construction. Numerous variations of excavation procedures, such as ripping and blasting, with its many variables, must be tested to determine what works best in each different rock type. For this reason, considerable flexibility must be written into a test quarry contract to allow the Contracting Officer's Representative (COR) to exercise control of the contractor's excavation procedures, including blast hole sizes, pattern spacing, depth of hole, subdrilling, stemming, type of explosives, powder factor, and loading configuration. Loading and hauling procedures also cause considerable variation in the rock gradation produced and are variables which should be within the control of the COR. A test quarry contract should not be an end-product type but should be a method type and essentially call for the contractor to furnish supervision, labor, materials, equipment, and supplies to proceed with test excavation(s) as directed by the COR.

7-2. Safety Considerations

Safety considerations pertaining to test quarry programs are as follows:

a. Operations. Test quarries are frequently located in areas of very steep terrain where access is very difficult. Rock excavation procedures also require operations which can be very dangerous unless all safety precautions are strictly followed. A safety analysis should be performed before any work begins to establish any added precautions that may be needed beyond those set forth in EM 385-1-1.

b. Affects on test quarry location. Access to the test quarry site is frequently a major problem because of very steep topography and because of the high cost of haul-road construction into such areas. Safety considerations limit the maximum grade to which haul roads may be constructed. Because of access-road cost, the decision is often made to locate the test quarry, not in the area where future construction is to take place, but in one with similar rock types. This may lead to test-quarry and test-fill results which are not totally applicable to the project construction. This can also result in later contractor claims and cost over-runs which are many times greater than if safe access roads to the planned required excavation area were constructed in the first place. If at all possible, the test quarry should be sited within the limits of the excavation area which has been selected as the main source of rock required for project construction. If the costs of doing so exceed the limitations of Preconstruction Engineering and Design funding, consideration should be given to making the test quarry and test fill contract(s) and the access road contract the first construction contract in order to transition from PED to Construction General (CG) funding. This will allow adequate monies to safely construct the test quarry in the most appropriate location(s).

7-3. Modification of Design

As data are obtained during the progress of the test quarry development, it becomes necessary to modify the test quarry design to take into consideration new information about the rock's behavior that was not available at the time of the original design. The test quarry contract specifications should be written to permit these changes at the direction of the COR (as discussed in paragraph 7-1). The test quarry modifications must be developed in full coordination between the TTQS and the designers to assure that all future needs for design information are being met.

7-4. Blasting Plans

Blasting plans should be required by the contract specifications. These are necessary to permit the TTQS to assure that the contractor's plan of operation is in accordance with the test-quarry design. Approval of the blasting plans by the COR should be required by the contract. In addition to the guidance contained in Chapter 5, detailed guidance on blasting techniques is contained in TM 5-332 and EM 1110-2-3800.

a. Master plan. The contract specifications should require the contractor to prepare and submit for review, modification (if necessary), and approval, a master plan of excavation prior to initiation of any excavation. This master plan should include a complete description of the contractor's proposed scheduling sequence, equipment, staffing, overburden removal and disposal/reclamation plans, drainage control, plans for ripping (if required), overall plan for each test blast, and loading and hauling procedures. The plan should also include a description of his provisions for modifications and/or changes to equipment and procedures as required by the COR as excavation progresses and information is developed on which to base such changes.

b. Individual plans. Prior to each blast, the contractor should be required to furnish a detailed blasting plan. This plan should show location of bench to be blasted (with respect to the overall excavation), presplit or smooth blasting plan for side slopes, depth of excavation, burden and free-face location, blast-hole pattern and powder factor, blast-hole diameters, subdrill, stemming, loading configuration, and delay sequence. This plan should be used by the TTQS as the basis to make any modifications deemed necessary to provide the desired breakage data. The contract should require approval of this plan by the COR prior to initiation of the work in the particular test area.

c. Blast reports. The contractor should be required to furnish a post-blast report which will detail any variation that occurred to the individual blasting plan as furnished prior to the blast. Such things as misfires, under or overloaded holes, water in the holes, variations in stemming, and any other observed variables should be reported. Video documentation is helpful in verifying and evaluating blast reports. Test quarry specifications can be written to include video documentation submittals to the TTQS. The TTQS and staff should prepare their own report of each blast. This should contain a description of the rock mass including rock type and condition, as-blasted gradations, condition of slopes, bottom configuration and depth of pull, location of the post-blast rock pile, slope mapping, photographic documentation of the slopes, bottom, and the rock pile before loading and hauling. Report conclusions should include an evaluation of the effectiveness of the blast in providing the design gradation, designed slopes, and bottom conditions. Recommended modifications to subsequent test blasts based on these results should be included in the report.

7-5. Slope Mapping and Presplitting Observations

One of the purposes of a test quarry is to develop blasting procedures which will result in safe, satisfactory permanent slopes. This will require the testing of different presplitting patterns. Different presplit hole spacings should be tested, usually varying from 46 cm (18 in.) to 91 cm (36 in.); different slope angles, usually varying from 1 vertical on 1 horizontal to 1 vertical on 0.25 horizontal; different loading configurations in the blast holes; and different widths of buffer zones between the presplit patterns and the production blast holes. The results of these variables are affected very much by the relationship of the orientation of rock mass structural details to the orientation of the excavation slopes. Slopes cut on one side of the excavation may be entirely satisfactory while those cut on the opposite side may be unsatisfactory and even unstable. Detailed guidance on presplitting techniques is contained in EM 1110-2-3800.

a. Mapping. The excavated slopes should be mapped. The conditions noted and mapped should include cut slope angle, slope height, presplit blast-hole spacing, condition of each slope segment, rock type and condition, and location and orientation of rock fractures intersecting the slope. In addition to mapping rock fractures in the slopes, fracture spacing/frequency should also be noted along judiciously located scan lines for comparison with similar information developed from the design investigations and with the measured rock-pile gradations. Visible groundwater and surficial infiltration seepage areas should also be depicted during mapping.

b. Presplitting observations. Each slope should be carefully described and reported as to its condition, taking into account the results of the presplitting and those factors such as intersecting rock fractures and rock quality which affect the stability of the slope. The maintenance of design blast-hole spacing and orientation is very important. Where these deviate from design, the results should be described. Successful presplitting normally leaves a half-round of the individual blast hole visible in the slope. Where these are not seen, it is likely that the presplit shot was too heavily loaded or that there was an insufficient buffer zone between the production blast and the presplit slope. If the presplit plane between blast holes is highly irregular, it is likely that the hole spacing was wider than optimum. Excessive rock fracturing behind the permanent slope line is another indication of excessive hole loading.

By contrast, incomplete shearing of the rock between presplit holes may be an indication that the holes were under loaded or that they were too widely spaced. Rock structure induced (wedge or planar) slope failures may occur. These features should be incorporated into the slope maps and should be described for inclusion in the final report. Complete photo coverage of the as-excavated slopes is of considerable value in illustrating the observation descriptions. These photographs should be obtained after the slope is freshly cut and used generously in the final report.

7-6. Rock Quality and Pre-Test Fill Gradations

a. Rock quality after blast. It is important to evaluate and describe the quality of the blasted rock existing in each blasted area. Rock quality is a major factor of the design of rockfill structures and it is important to compare the rock quality observed from the test quarry program with the design assumptions. In addition, variations in rock quality often become the basis for disputes between the contractor and the government. Because of the uniqueness of each site and each rock type, rock quality evaluation systems should be designed on the conditions encountered in each test quarry program. Such evaluation systems should include, as a minimum: rock type, degree of weathering (unweathered, slightly weathered, moderately weathered, highly weathered, decomposed, EM 1110-1-1804), potential for degradation, both in stock piles and during fill placement and compaction (e.g., estimates of abrasion resistance, desiccation deterioration, incipient fractures, brittleness, softness, and physical or chemical instability), and rock mass gradation.

b. Pretest fill gradations. As part of the rock mass quality evaluation, it is important to develop information on the degree of degradation that occurs during the loading, hauling, processing, storage, and placement of rock fill in an embankment. In order to obtain this information, it is necessary to determine the gradations that exist after blasting but before loading, hauling, placement, and compaction. This should be done by the same procedures which will be used to control the gradation of fill placed in the test fills and subsequently in the embankment. Methods for obtaining mechanical gradations of rock fill were addressed in paragraph 6-5 and will be treated in more detail in Part 2: Test Fills. In addition to the mechanical grading methods, particle size scan-line measurements of the blasted rock pile should be performed and their accuracy evaluated. If particle shape and percentage of fines allow these types of measurements, they are a rapid, economical adjunct to time-consuming screen gradation measurements. A comparison of the initial rock mass gradation with gradations made at subsequent stages in the process of rock placement in test fills will provide data on which to base an appraisal of rock mass degradation that can be expected during loading, hauling, and embankment construction. If there is potential for the rock to deteriorate over time in a stock pile, this too should be evaluated. One approach is to establish test stock piles and perform initial and subsequent gradation tests and compare the results. A complication can develop in this test because the mechanical action of the test itself may tend to degrade the particles of the test specimen. This must be considered in evaluating the results. Hairline blast fractures develop in some brittle rock types. Because these fractures allow degradation of particle size during handling, processing, placement, compaction, and project operation, they need to be identified during this stage of test quarry development. Samples of varying particle size should be furnished to the appropriate Division Laboratory for testing to determine the presence of minute blast-induced fractures.

7-7. Rock Processing Results

Frequently, rockfill embankment designs require rock processing that goes beyond the quarry-run gradations that can be produced by the rock excavation procedures in the quarry. These can include simply processing the rock over a grizzly to separate it into two or three different sizes to the much more complex process of running the rock through a crusher and vibrating screens to produce a series of carefully controlled gradations. The more processing required, the more expensive the embankment construction will likely be. In addition, it is likely that there will be more opportunity for disputes between the contractor and government. If the design efforts indicate that processing will be required during construction, it is important to test it during the test-quarry and test-fill operations. Otherwise, the results from the test quarry and test fill may not be indicative of the results to be obtained during final construction. The gradations obtained from rock processing are the results of many variables. These include rock type, rock quality, excavation method, and rock crushing and screening plant design. It is frequently difficult for a smaller test quarry and portable processing equipment to reproduce the results that will be obtained from a full quarry and large production equipment. For these and other reasons, it is desirable to design the embankment to require as little processing as is possible and to construct the test fills with materials that are truly representative of those that will be obtained from the construction production excavations. Rock processing results should be carefully described in the Test Quarry and Test Fill Report.

7-8. Report

The data and information developed during the test quarry construction should be analyzed, evaluated, and reported in a Test Quarry and Test Fill Report. The test quarry portion of the report should contain sketches of each test blast, maps of all excavated slopes and bottoms, descriptions of the results of each test blast including presplit slopes, gradations of the quarry-run material produced by each blast in each separate rock type, and conclusions and recommendations. The report should be generously illustrated with geologic maps and cross sections, sketches, photographs, analyses of the rock fracture orientations and frequency/spacing revealed in the excavations and evaluations of the fracture orientation and spacing to slope stability to the blasted rock gradations produced. A typical outline of the test quarry section of the report is shown in Table 7-1. The report of the test quarry program is a very important document for use during final design and construction. Also, it can prove to be very valuable during the contract disputes which inevitably arise during the complicated construction of a large dam. The importance of a complete, accurate, well-conceived report cannot be overemphasized. The conclusions and recommendations section of the report should be specific with regard to the suitability of the rock materials for the uses to which it will be placed. Constraints upon the suitability of the materials must be clearly stated (e.g., shale partings in a rock mass will likely lead to an eventual breakdown in particle size). Recommendations for any special handling, processing, storage or placement methods that were developed during the test quarry operation should be clearly detailed in that section of the report.

Table 7-1
Typical Test Quarry Report Outline

1. Executive Summary

2. Introduction

3. Test Quarry Design and Objectives

   a. Discussion of objectives
   b. Overview of site selection criteria
   c. Thorough presentation of design including layout and slope stability

4. Geological Conditions in the Test Quarry

5. Description of Each Test Blast

   a. Rock type and condition
   b. Hole pattern
   c. Delay pattern
   d. Hole depths and loading design
   e. Explosives, detonators, and delays
   f. Blasted rock mass description
   g. Quarry-run gradation
   h. Laboratory test results
   i. Conclusions

6. Drilling, Loading, and Hauling Equipment and Procedures

7. Description of the Results of Each Presplit Slope Blast

   a. Rock type and condition
   b. Presplit hole and explosive charge configuration
   c. Presplit slope condition
   d. Rock joint analysis and slope stability
   e. Conclusions

8. Rock Processing Results

   a. Description of processing objectives
   b. Description of rock processing equipment
   c. Results of processing each rock type and condition
   d. Gradations and particle shapes
   e. Degradation during each stage of processing
   f. Laboratory test results

9. Conclusions and Recommendations

   a. Conclusions including lessons learned
   b. Recommendations

APPENDICES -- Laboratory Test Sheets, Boring Logs, Field Gradation Test Results, Description of Rock Processing Equipment, Photographic Documentation, Etc.