Chapter 6
Large-scale, Prototype Investigations

6-1. Prototype Test Programs

Whenever the size and complexity of a project warrant, large-scale, prototype test programs can yield information unavailable by any other method. Because these investigations are expensive and require the services of a construction contractor in most cases, they are commonly included as part of a main contract to confirm design assumptions. However, if performed during the PED phase, they can provide a number of benefits that will result in an improved, more cost-effective design. These benefits include: confirmation of assumptions for new or innovative design, improved confidence level allowing reduced safety factors, proof of constructibility, confirmation of environmental compliance, and greater credibility in allaying public concerns. Evaluation of the potential for savings and benefits should be made by an experienced engineering geologist or geotechnical engineer. A major pit-fall of the large-scale prototype test is that it is commonly difficult, if not impossible, to precisely follow the same procedures in the main contract that were used in the test. This does not eliminate the benefits to be gained but should be kept in mind when deciding how to incorporate the information into a bid package.

Section I
Test Excavations and Fills

6-2. Accomplishments

In most cases, a test excavation or fill technique such as blasting and rippability accomplishes one or more of the following requirements: (a) evaluates the suitability of specialized construction equipment such as coal saws or vibratory rollers; (b) investigates the influence of material properties on construction products such as blasted rock gradations; (c) provides the opportunity for preconstruction monitoring of ground reactions to test design assumptions; (d) more completely discloses the geologic conditions; (e) investigates material placement properties and procedures; (f) investigates environmental impacts such as blasting vibrations or ground water lowering; and (g) provides access to install initial ground support and instrumentation.

6-3. Test Quarries

Test quarries are usually implemented in conjunction with test fill programs and in areas where large quantities of rock material will be needed from undeveloped sources. EM 1110-2-2301 discusses test quarry and test fill evaluation procedures. 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 investigation. If 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 ensures maximum side slope stability by minimizing overbreakage. Mapping of test

quarry slopes, in conjunction with the use of slope stability analysis programs such as ROCKPACKII (Watts 1996) and Discontinuous Deformation Analysis Program (International Forum on Discontinuous Deformation Analysis and Simulations of Discontinuous Media 1996), 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 ground water 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 an adequate quality and quantity of fill and construction material and the range of aggregate size has been determined, 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 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.

c. Test program. In a well-planned test quarry program, many of the blasting variables, such as blasthole spacing, patterns, and firing sequences, powder brisance, powder factor, and bench height, 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. If 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 EM 1110-2-2301, Bechtell (1975), Lutton (1976), and Bertram (1979).

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. These results, combined with results of test fills, form a valuable source of data for the quarry designer. This

information is equally valuable to prospective contractors and should be provided for information in the plans and specifications.

6-4. Exploratory Tunnels

Exploratory tunnels permit detailed examination of the composition and geometry of rock structures such as joints, fractures, faults, shear zones, other discontinuities, and solution channels. They are commonly used to explore conditions at the locations of large underground excavations and the foundations and abutments for large dams. 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. Although expensive, exploratory tunnels provide exceptionally good preconstruction information to perspective contractors on major underground projects and can reduce bid contingencies and/or potential for claims. Long horizontal exploratory drill holes can also be used in lieu of, or in combination with, pilot tunnels to gather information about tunneling conditions prior to mining.

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 and/or consolidation grouting for critical areas of the full tunnel, or in some cases, to provide relief or "burn cuts" to facilitate blasting. Exploratory tunnels that are strategically located commonly 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. One concern, however, is not to position the pilot tunnel too close to the projected crown excavation neat line of the full-sized tunnel. If this occurs, overbreak in the crown of the tunnel can have a negative impact on mining and stabilizing the crown of the full-sized tunnel.

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 insignificant compared to the cost of the tunnel and support system. The geologic information gained from such mapping provides a very useful dimension to interpretations of rock structure deduced from exposures in surface outcrops. A complete picture of the site geology can be achieved only if the geologic data and interpretations from surface mapping, borings, and pilot tunnels are combined and well correlated. Such analyses are best carried out using a GIS.

6-5. Test Fills and Trial Embankments

a. Test fills. Test fills are generally recommended where unusual soils or rockfill materials are to be compacted or if newly developed and unproven compaction equipment is to be employed. 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 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, COE 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 EM 1110-2-1911 and Hammer and Torrey (1973).

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. For example, trial embankments were constructed at Laneport, TX (Parry 1976), Warm Springs, CA (Fagerburg, Price, and Howington 1989), and R. D. Bailey, WV Dams (Hite 1984).

(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 methods 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 only be determined by analyzing existing slopes or constructing trial embankments. If 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.

Section II
Test Grouting

6-6. Purpose

Test grouting operations are 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 programs provide information necessary to formulate procedures and determine design specifications, costs, and appropriate equipment. Test grouting consists of performing experimental grouting operations on exploratory boreholes to determine the extent to which the subsurface materials are groutable. A well-conceived and 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 necessary for development of a satisfactory test grouting program are discussed in detail in TM 5-818-6, and EM 1110-2-3506.

6-7. Test Grouting 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 because this procedure is initially directed at the source of water seepage. Circle grouting is a more comprehensive test procedure. Multiple line grouting is also a comprehensive grout testing procedure but does not require as many grout holes as the circle grouting test.

6-8. Test Grouting 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 test 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. 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.

6-9. Record Keeping

Meaningful evaluation of a grouting program is impossible without adequate record keeping. Variables that are pertinent in grouting are discussed in detail in TM 5-818-6 and EM 1110-1-3500 and will not be repeated here. They are numerous and unless the record keeping aspect of grouting is well-organized and given top priority, the value of the test grouting program will be lost. Records have traditionally been kept by hand on specially prepared forms. The Grouting Database Package (Vanadit-Ellis et al. 1995), a

PC-based, menu-driven program that stores and displays hole information, drilling activities, water pressure tests, and field grouting data is an improvement over manual record keeping methods and is available through USAEWES.

Section III
Piling Investigations

6-10. Piling Investigation Benefits

Piling investigations may be conducted prior to construction or, more commonly, as part of a construction project just prior to the start of production pile driving. Predicting the performance of driven piles has been extensively studied, and various methods, including some very sophisticated computer analyses, are available to the designer. While these are useful and adequate for predicting piling performance for small jobs, projects requiring large numbers of piles generally benefit from a preconstruction piling investigation. This is because the methods of analysis that are commonly used are conservative and may significantly underestimate the actual working capacity of pilings. In addition to providing reliable design load capacities, field tests can help answer questions such as: how much penetration into rock can be expected, what time-dependent effects can be expected, and do hard layers exist that will cause early refusal or make driving points a necessity? As in all aspects of geotechnical engineering, pile testing is subject to a margin of error which is dependent on the heterogeneity of the site being investigated. Where the site geology is very complex, the data from one pile load test will probably not be repeatable across the project site. In addition, the performance and efficiency of a pile driving hammer can vary tremendously, even for hammers with the same energy rating. Because the capacity of a pile is heavily influenced by the hammer, the results from a test program cannot be translated to the production piles on the final project without some reservations. All of these considerations aside, there are times when a pile testing program will result in a significant savings to a project or, at least, a high confidence level in the piles capacity. EM 1110-2-2906 provides detailed information of pile foundation design.

6-11. Driving Records

As with grouting, adequate evaluation of a pile driving job cannot be performed without adequate records. A sample form for recording pile driving data is shown in Figure 6-1. This form can be modified to meet particular designer's needs but generally lists the information that is of most interest.

6-12. Load Testing

The correct procedures for conducting a pile load test are given in numerous references including EM 1110-2-2906 and are not repeated here. Generally, a pile will be tested for axial load capacity, both in compression and tension, and for lateral resistance.

DAILY PILE RECORD FOR LARGE- AND SMALL-DIAMETER BORED PILES

PILE RECORDS TO BE SUBMITTED TO OFFICE DAILY
A SEPARATE SHEET TO BE USED FOR EACH PILE

BLOCK NUMBER			DRAWING NUMBER / /			
1. General	Pile reference number		Pile diameter		Level of base	
			Underream diameter			
	Ground level		Cutoff level		Concreted level	
2. Drilling	Date started		Date completed			
	Error in position on plan					
3. Obstructions[1] Natural/ Unnatural	Type		Depth encountered		Penetration time	
	Type		Depth encountered		Penetration time	
4. Steel[1] main steel links or helix	Number of bars		Diameter		Length	
	Centers of bars/pitch		Diameter		Cover to all steel	
5. Concrete	Date started		Date completed		Concrete temperature	Quantity Actual: Theoretical:
	Mix		Slump		Supplier	
6. Borehole log and rock excavation	Depth of soil	Description of soil	Depth of rock	Description of rock	Depth of rock augered	Depth of rock chiseled
7. Casing[1]	Depth of temporary casing		Depth of permanent casing		Reason for use of permanent casing	
8. Water[1]	Depth encountered		Details of strong flow		Details of remedial measures	
	Depth to strong flow					

[1] If there are no changes to be recorded, items 3, 4, 7, and 8 need be completed for the first pile only in each block.

Remarks:

Signed: **Site Contract Engineer:**

Figure 6-1. Example of a piling log. Modified from Tomlinson (1994)