Chapter 11
Construction Considerations

11-1. Scope

This chapter provides general guidance for factors to be considered in the construction of foundations and cut slopes excavated in rock masses. The chapter is divided into five sections with general topic areas to include: Excavation; Dewatering and Ground Water Control; Ground Control; Protection of Sensitive Foundation Materials; and Excavation Mapping and Monitoring.

Section I
Excavation

11-2. Information Requirements

The factors that should be considered when determining the applicability of an excavation method fall into two groups. The first group includes the characteristics of the rock mass to be excavated. The more important of these characteristics are hardness or strength of the intact rock, and the degree of fracturing, jointing, bedding, or foliation of the rock mass. This information will normally have been acquired during routine exploration. The second group of factors includes features of the foundation design. These features are the size and shape of the excavation, the tolerances required along the excavation lines, and any restrictions on the time allowed for the excavation to be completed. This second group of factors determines the amount of material to be excavated, the required rate of excavation, the type of finished excavation surface the work must produce, and the amount of working space available.

11-3. Excavation Methods

A number of methods are available for excavating rock. These methods include drill and blast, ripping, sawing, water jets, roadheaders and other mechanical excavation methods.

a. Drill and blast. Drill and blast is the most common method of excavating large volumes of rock. The hardness of some rock types may eliminate most other excavation techniques from consideration for all but the smallest excavations. Blasting methods can be adapted to many variations in site conditions. Drill and blast techniques, materials, and equipment are thoroughly discussed in EM 1110-2-3800 and the Blasters Handbook (Dupont de Nemours and Company 1977). Due to the availability of that manual, the basics of blasting will not be discussed here. The emphasis of this section will be on aspects of design and construction operations that must be considered when blasting is to be used as a foundation excavation method.

(1) Minimizing foundation damage. Blasting may damage and loosen the final rock surfaces at the perimeter and bottom of the excavation. Although this damage cannot be eliminated completely, in most cases it can be limited by using controlled blasting techniques. The more common of these techniques are presplitting, smooth blasting, cushion blasting, and line drilling.

(a) When presplitting, a line of closely spaced holes is drilled and blasted along the excavation line prior to the main blast. This process creates a fracture plane between the holes that dissipates the energy from the main blast and protects the rock beyond the excavation limits from damage.

(b) For the smooth blasting method, the main excavation is completed to within a few feet of the excavation perimeter. A line of perimeter holes is then drilled, loaded with light charges, and fired to remove the remaining rock. This method delivers much less shock and hence less damage to the final excavation surface than presplitting or conventional blasting due to the light perimeter loads and the high degree of relief provided by the open face.

(c) Cushion blasting is basically the same as smooth blasting. However, the hole diameter is substantially greater than the charge diameter. The annulus is either left empty or filled with stemming. The definitions of smooth and cushion blasting are often unclear and should be clearly stated in any blasting specifications.

(d) When using the line drilling method, primary blasting is done to within two to three drill hole rows from the final excavation line. A line of holes is then drilled along the excavation line at a spacing of two to four times their diameter and left unloaded. This creates a plane of weakness to which the main blast can break. This plane also reflects some of the shock from the main blast. The last rows of blast holes for the main blast are drilled at reduced spacing and are lightly loaded. Line drilling is often used to form corners when presplitting is used on the remainder of the excavation.

(e) To minimize damage to the final foundation grade, generally blast holes should not extend below grade. When approaching final grade, the rock should be removed in shallow lifts. Charge weight and hole spacing should also be decreased to prevent damage to the final surface. Any final trimming can be done with light charges, jackhammers, rippers, or other equipment. In certain types of materials, such as hard massive rock, it may be necessary to extend blast holes below final grade to obtain sufficient rock breakage to excavate to final grade. This procedure will normally result in overbreak below the final grade. Prior to placing concrete or some types of embankment material, all loose rock fragments and overbreak must be removed to the contractual standard, usually requiring intense hand labor. The overexcavated areas are then backfilled with appropriate materials.

(2) Adverse effects of blasting. Blasting produces ground vibrations, airblast, and flyrock which affect the area around the site. These effects should be kept to a minimum so that nearby structures and personnel are not damaged, or injured and complaints from local residents are kept to a minimum.

(a) Ground vibration is the cause of most complaints and structural damage. Ground vibration is usually expressed in terms of peak particle velocity, which can be estimated for a certain location using the equation

$$V = H(D/W^{1/2})^{-B} \tag{11-1}$$

where

V = peak particle velocity in one direction, inches per second (ips)

D = distance from blast area to point particle velocity of measurement, ft

W = charge weight per delay, lbs

H, B = constants

The constants, H and B, are site-specific and must be determined by conducting test blasts at the site and measuring particle velocities with seismographs at several different distances in different directions. By varying the charge weight for each blast, a log-log plot of peak particle velocity versus scaled distance ($D/W^{1/2}$) may be constructed. The slope of a best fit straight line through the data is equal to the constant B and the value of velocity at a scaled distance of 1 is equal to the constant H. After determining the constants H and B, Equation 11-1 can then be used to estimate the maximum charge weight that can be detonated without causing damage to nearby structures. If test blasts are not conducted at the site to determine the propagation constants, the maximum charge weight may be estimated by assuming a value for the scaled distance. A value of 50 ft/lb$^{1/2}$ is considered a minimum safe scaled distance for a site for which no seismograph information is available. Using this value,

$$D/W^{1/2} = 50 \text{ ft/lb}^{1/2} \tag{11-2}$$

and

$$W = \left(\frac{D}{50}\right)^2 \tag{11-3}$$

where W is the maximum safe charge weight per delay in pounds. The maximum safe peak particle velocity for most residential structures is approximately 2 ips. Ground vibration exceeding this level may result in broken windows, cracked walls or foundations, or other types of damage. Blasts fired with a high degree of confinement, such as presplit blasts, may cause higher particle velocities than those predicted by the vibration equation. This is due to the lack of relief normally provided by a free excavation face.

(b) Airblast, or compression waves travelling through air, may sometimes damage nearby structures. Noise is that portion of the airblast spectrum having wave frequencies of 20-20,000 Hz. Atmospheric overpressure is caused by the compression wave front. This overpressure may be measured with microphones or piezoelectric pressure gauges. An overpressure of 1 psi will break most windows and may crack plaster. Well-mounted windows are generally safe at overpressures of 0.1 psi, and it is recommended that overpressures at any structure not exceed this level. Airblast is increased by exposed detonating cord, lack of sufficient stemming in blast holes, insufficient burden, heavy low-level cloud cover, high winds, and atmospheric temperature inversions. All of these conditions should be avoided during blasting. Temperature inversions are most common from 1 hour before sunset to 2 hours after sunrise. Blasting should be avoided during these hours if airblast is a concern.

(c) Flyrock is usually caused by loading holes near the excavation face with too heavy a charge or by loading explosives too close to the top of the holes. These conditions should be avoided at all times. Flyrock may also be controlled with blast mats. These are large woven mats of wire or rope which are laid over the blast holes or on the face to contain flying debris. Blast mats should be used when blasting very close to existing structures. Extreme caution must be used when placing blast mats to prevent damage to exposed blasting circuits. An alternative to a blasting mat is to place a layer of soil a few feet thick over the blast area prior to blasting to contain the flyrock.

(d) Complaints or claims of damage from nearby residents may be reduced by designing blasts to minimize the adverse effects on the surrounding area as much as possible while still maintaining an economic blasting program. To aid in the design of the production blast, test blasts should be conducted and closely monitored to develop attenuation constants for the site. The test blasts should be conducted at several loading factors in an area away from the production blast area or at least away from critical areas of the excavation. However, even with careful blast design, some claims and complaints will most likely occur. People may become alarmed or claim damage when vibration and airblast levels are well below the damage threshold. There are several steps that may be taken to protect against fraudulent or mistaken damage claims. The most basic step is to maintain accurate records of every blast. The blasting contractor is required to submit a detailed blast plan far enough in advance of each shot to allow review by the Government inspector. The blast plan should give all the details of the blast design. After each blast, the contractor should submit a blast report giving the details of the actual blast layout, loading, results, and all other pertinent data. A blast plan and report are normally required on Corps projects. The ground vibrations and airblast from each blast may also be recorded at the nearest structures in several different directions. The seismograph records can be used in the event of a claim to determine if ground vibrations may have reached potentially damaging levels. It is also good practice to record all blasts on videotape. A video-taped record can be helpful in solving various problems with the blasting operations. These monitoring records should be kept, along with the blast plans and records, as a record of the conditions and results of each blast.

(e) A further precaution to be taken to protect against damage claims is to require that the contractor perform a preblasting survey of structures near the blasting area. The purpose of the survey is to determine the condition of nearby structures prior to blasting. The survey should include recording all cracks in plaster, windows, and foundations and photographing the buildings inside and out. The preblast survey might also include basic water quality analyses from any wells in the area. It should also be determined during the survey if there is any sensitive or delicate equipment in nearby buildings that may limit the acceptable peak particle velocity to a value less than the normal 2 ips. This survey should be done at no cost to the property owners. If any property owner refuses to allow his property to be inspected, he should be asked to sign a statement simply stating that he declined the service. The results of the survey will help in determining if damage was pre-existing or is blast-related. The scope of the test blasting, monitoring, and preblast survey will be dependent upon the size and duration of the production blasting and the anticipated sensitivity of the area as determined by the population density and other social and environmental factors.

(f) The key to blasting safety is experienced, safety-conscious personnel. All field personnel directly involved with a blasting operation must be thoroughly familiar with the safety rules and regulations governing the use of explosives. Information and rules on blasting safety are available from explosives manufacturers or the Institute of Makers of Explosives. Safety regulations that apply to Corps of Engineers projects are stated in EM-385-1-1, Safety and Health Requirements, Section 25. These regulations shall be strictly adhered to under all circumstances. The contractor should be required to conduct operations in compliance with all safety regulations. Any unsafe practices must be immediately reported and corrected to avoid accidents.

b. Ripping. Ripping is a means of loosening rock so it may be excavated with loaders, dozers, or scrapers. It involves the use of one or more long narrow teeth which are mounted behind a crawler tractor. Downward pressure is exerted by the tractor and the teeth are pulled through the rock. In addition to standard rippers, impact rippers have been developed in recent years that are capable of breaking relatively strong rock.

(1) Factors influencing rippability. The rock's susceptibility to ripping is related to the rock structure and hardness. The rock structure, in the form of joints, fractures, bedding, faulting, or other discontinuities, determines to a large degree the rippability of the rock mass. These discontinuities represent planes of weakness along which the rock may separate. Rock with closely spaced, continuous, near horizontal fractures is much more easily ripped than rock with widely spaced, discontinuous, high angle fractures. Rock hardness influences the rippability by determining the amount of force that must be exerted by a ripper tooth to fracture the intact rock. Rock type, fabric, and weathering can be related to the rippability of a rock mass because of the influence they have on the

rock structure and hardness. Sedimentary rocks are generally easiest to rip because of their laminated structure. Igneous rock are generally difficult to rip because they are usually hard and lack well-developed lamination. Any weathering that takes place reduces the hardness of the rock and creates additional fractures, making the rock easier to rip. Due to its lesser degree of homogeneity, rock with a coarse grained fabric is generally weaker than fine grained rock. Because of this, coarse grained rock is usually easier to excavate by ripping than finer grained rock types.

(2) Rippability indicators. Seismic wave velocity is often used as an indicator of the rippability of a rock mass. The seismic wave velocity is dependent on the rock density or hardness and the degree of fracturing. Hard, intact rock has a higher seismic velocity than softer, fractured rock. Therefore, rocks with lower seismic velocities are generally more easily ripped than those with higher seismic velocities. The seismic wave velocity may be measured using a refraction seismograph and performing a seismic survey of the excavation site. To determine the rippability of the rock, the seismic wave velocity must then be compared with the seismic wave velocities of similar materials in which ripper performance has been demonstrated. Tractor manufacturers have published charts showing, for a particular size tractor and specific ripper configuration, the degree of rippability for different rock types with varying seismic velocities. The rippability of a rock mass may also be assessed by using a rock mass rating system developed by Weaver (1975). Using this system, various rock mass parameters are assigned numerical ratings. The numerical values are then added together to give a rippability rating. Lower ratings indicate easier ripping. Using tractor manufacturer's charts, this rating can be correlated to production rate for various tractor sizes.

(3) Contract considerations. It should never be stated in contract specifications or other legal documents that a rock is rippable or inability to rip designates a new pay item without specifying the tractor size, ripper configurations and cubic yards loosened per hour (for pay purposes) for which the determination of rippability was made. Rock that may be rippable using a very large tractor may not be rippable using smaller equipment. Not including this qualifying information may lead to claims by a contractor who, after finding he is unable to rip the rock with the size equipment he has available, claims the contract documents are misleading or incorrect.

(4) Other considerations. Ripping may be used to remove large volumes of rock in areas large enough to permit equipment access. However, ripping produces very poorly sorted muck with many large blocks of rock. Muck from ripping may require further breaking or crushing to make it suitable for use as fill or riprap.

c. Sawing. Sawing is not a common practice, although it is sometimes used as a way of trimming an excavation in soft rock to final grade. Saws may also be used to cut a slot along an excavation line prior to blasting or ripping as an alternative to line drilling. One of the advantages of sawing is that it produces a very smooth excavation face with minimal disturbance to the remaining rock. It also gives very precise control of the position of the final excavation face and may be used to finish fairly complex excavation shapes. Coal saws have been used for sawing soft rocks. Concrete saws may be used for very small scale work in harder material.

d. Water jets. High pressure water jets are beginning to find uses as excavation tools in the construction industry. Water jets cut rock through erosion and by inducing high internal pore pressures which fail the rock in tension. Water jets may range from large water canon to small hand-held guns. Extremely hard rock may be cut with water jets. However, the pressures required to cut hard rock are extremely high. Optimum pressures for cutting granite may be as high as 50,000 psi. Water jets may be used for cutting slots, drilling holes, trimming to neat excavation lines, cleaning loose material from an excavated surface. Drill holes may also be slotted or belled. Water jets may not be suitable for use in formations which are extremely sensitive to changes in moisture.

e. Roadheaders. Roadheaders, which are often used in underground excavation, may also be used for final trimming of surface excavations. Roadheaders can rapidly and accurately excavate rock with little disturbance to the remaining rock mass. However, due to power and thrust limitations, their use is limited to rock with a unconfined compressive strength less than approximately 12,000 psi. Large machines may have very high electrical power requirements. Cutting capabilities, length of reach, and power requirements vary widely between models and manufacturers.

f. Other mechanical excavation methods. Various types of mechanical impactors or borehole devices are sometimes used in rock excavation. Mechanical impactors may include hand-operated jackhammers, tractor-mounted rock breakers, or boom-mounted hydraulic impact hammers. These all use chisel or conical points that are driven into the rock by falling weights or by hydraulic or pneumatic hammers. Wedges or hydraulic borehole jacks may be driven or expanded in boreholes to split the rock. Chemicals have been developed which are placed in boreholes much like explosives and, through rapid crystal growth, expand and fracture the rock. Wedges, borehole jacks, or expanding chemicals may provide alternative means of excavation in areas where the vibration and noise associated with blasting cannot be tolerated because of nearby structures or sensitive equipment. Because of their generally low production rates, these alternative methods are normally used only on a limited basis, where excavation quantities are small or for breaking up large pieces of muck resulting from blasting or ripping. Crane-mounted drop balls are also often used for secondary muck breakage. Jackhammers may be used in confined areas where there is not sufficient room for most equipment to operate.

11-4. Effects of Discontinuities on Excavation

a. Overbreak. The amount of overbreak, or rock breakage beyond intended excavation lines, is strongly affected by the number, orientation, and character of the discontinuities intersecting the faces of the excavation. Discontinuities represent preferred failure planes within the rock mass. During excavation the rock will tend to break along these planes. In rock with medium to closely spaced joints that intersect the excavation face, overbreak will most likely occur and will produce a blocky excavation surface. If joints run roughly parallel to the excavation face, overbreak may occur as slabbing or spalling. Worsey (1981) found that if a major joint set intersected the excavation face at an angle less than 15 degrees, presplit blasting had little or no beneficial effect on the slope configuration. When blasting, overbreak will also be more severe at the corners of an excavation. Overbreak increases construction costs by increasing muck quantities and backfill or concrete quantities. Because of this, the excavation should be planned and carried out in a way that limits the amount of overbreak. Special measures may be required in areas where overbreak is likely to be more severe because of geologic conditions or excavation geometry. These measures may include controlled blasting techniques or changes in the shape of the excavation.

b. Treatment of discontinuities. Sometimes, open discontinuities must be treated to strengthen the foundation or prevent underseepage. Open discontinuities encountered in bore holes below the depth of excavation may be pressure grouted. Open joints and fractures, solution cavities, faults, unbackfilled exploratory holes, or isolated areas of weathered or otherwise unacceptable rock may be encountered during the excavation process. These features must be cleaned out and backfilled. When these features are too small to allow access by heavy equipment normally used for excavation, all work must be done by hand. This process is referred to as dental treatment. Any weathered or broken rock present in the openings is removed with shovels, hand tools, or water jets. The rock on the sides of the opening should be cleaned to provide a good bond with the concrete backfill. Concrete is then placed in the opening, usually by hand.

Section II
Dewatering and Ground Water Control

11-5. Purposes

Dewatering of excavations in rock is performed to provide dry working conditions for men and equipment and to increase the stability of the excavation or structures. Most excavations that are left open to precipitation or that extend below ground water will require some form of dewatering or ground-water control. Evaluation of the potential need for dewatering should always be included in the design of a structure. Construction contract documents should point out any known potential dewatering problems by the field investigation work.

11-6. Planning Considerations

The complexity of dewatering systems varies widely. Small shallow excavations above ground water may require only ditches to divert surface runoff, or no control at all if precipitation and surface runoff will not cause significant construction delays. Extensive dewatering systems utilizing several water control methods may be required for larger deeper excavations where inflow rates are higher and the effects of surface and ground-water intrusion are more severe. It must be determined what ground-water conditions must be maintained during the various stages of the construction of the project. The dewatering system must then be designed to establish and maintain those conditions effectively and economically. The size and depth of the excavation, the design and functions of the planned structure, and the project construction and operating schedule must all be considered when evaluating dewatering needs and methods. The dewatering methods must also be compatible with the proposed excavation and ground support systems. The dewatering system should not present obstacles to excavation equipment or interfere with the installation or operation of the ground support systems. The rock mass permeability and existing ground-water conditions must be determined to evaluate the need for, or adequately design, a ground-water control system. The presence and nature of fracture or joint-filling material and the hardness or erodibility of the rock should also be determined to assess the potential for increasing flows during dewatering due to the enlargement of seepage paths by erosion.

11-7. Dewatering Methods

Dewatering refers to the control of both surface runoff and subsurface ground water for the purpose of enhancing construction activities or for improving stability.

a. Surface water control. Runoff and other surface waters should be prevented from entering the excavation by properly grading the site. Ditches and dikes may be constructed to intercept runoff and other surface water and direct it away from the work area. Ponding of water on the site should be prevented. Ponded water may infiltrate and act as a recharge source for ground-water seepage into the excavation.

b. Ground-water control. Ground water may be controlled by a number of different methods. The more commonly used methods include open pumping, horizontal drains, drainage galleries, wells, and cutoffs.

(1) Open pumping. When dewatering is accomplished with the open pumping method, groundwater is allowed to enter the excavation. The water is diverted to a convenient sump area where it is collected and pumped out. Collector ditches or berms constructed inside the excavation perimeter divert the water to sumps. Pumps are placed in pits or sumps to pump the water out of the excavation. Most large excavations will require some form of open pumping system to deal with precipitation. In hard rock with clean fractures, fairly large ground-water flows can be handled in this manner. However, in soft rock or in rock containing soft joint filling material, water flowing into the excavation may erode the filling material or rock and gradually increase the size of the seepage paths, allowing flows to increase. Other conditions favorable for the use of open pumping are low hydraulic head, slow recharge, stable excavation slopes, large excavations, and open unrestricted work areas. Open-pumping dewatering systems are simple, easily installed, and relatively inexpensive. However, dewatering by open pumping does not allow the site to be drained prior to excavation. This may result in somewhat wetter working conditions during excavation than would be encountered if the rock mass were predrained. Another disadvantage is that the water pressure in low permeability rock masses may not be effectively relieved around the excavation. This method should not be used without supplementary systems if the stability of the excavation is dependent on lowering the piezometric head in the surrounding rock mass. Because the drainage system lies inside the excavation, it may interfere with other construction operations. In some cases, it may be necessary to overexcavate to provide space for the drainage system. If overexcavation is required, the cost of the system may become excessive.

(2) Horizontal drains. Horizontal drains are simply holes drilled into the side of the excavation to intercept high angle fractures within the rock mass. The drain holes are sloped slightly toward the excavation to allow the water to drain from the fractures. The drains empty into ditches and sumps and the water is then pumped from the excavation. This is a very effective and inexpensive way to relieve excess pore pressure in the rock mass behind the excavation sides or behind a permanent structure. The drain holes can be drilled as excavation progresses downward and do not interfere with work or equipment operation after installation. When laying out drain hole locations, the designers must make sure they will not interfere with rockbolts or concrete anchors.

(3) Drainage galleries. Drainage galleries are tunnels excavated within the rock mass outside the main excavation. Drainage galleries normally are oriented parallel to the excavation slope to be drained. Radial drain holes are drilled from the gallery to help collect the water in fractures and carry it into the drainage gallery, where it is then pumped out. Drainage galleries must be large enough to permit access of drilling equipment for drilling the drain holes and future rehabilitation work. This method is effective in removing large quantities of water from the rock mass. Drainage galleries can be constructed prior to the foundation excavation using conventional tunnel construction methods to predrain the rock mass and they may be utilized as a permanent part of the drainage system for a large project. However, they are very expensive to construct and so are only used when water must be removed from a large area for extended periods of time.

(4) Wells. Pumping wells are often used to dewater excavations in rock. Wells can be placed outside the excavation so they do not interfere with construction operations. Wells also allow the rock mass to be predrained so that all excavation work is carried out under dry conditions. Wells are capable of producing large drawdowns over large areas. They are also effective for dewatering low to medium angle fractures that may act as slide planes for excavation slope failures. They will not effectively relieve the pore pressure in rock masses in which the jointing and fracturing is predominantly high

angled. The high angle fractures are not likely to be intersected by the well and so will not be dewatered unless connected to the well by lower angled fractures or permeable zones. The operating cost of a system of pumping wells can be high due to the fact that a pump must operate in each well. Power requirements for a large system can be very high. A backup power source should always be included in the system in the event of failure of the primary power source. Loss of power could result in failure of the entire system.

(5) Cutoffs. Ground-water cutoffs are barriers of low permeability intended to stop or impede the movement of ground water through the rock mass. Cutoffs are usually constructed in the form of walls or curtains.

(a) Grouting is the most common method of constructing a cutoff in rock. A grout curtain is formed by pressure grouting parallel lines of drill holes to seal the fractures in the rock. This creates a solid mass through which ground water cannot flow. However, complete sealing of all fractures is never achieved in grouting. The effectiveness of a grout curtain is difficult to determine until it is in operation. Measurements of changes in grout injection quantities during grouting and pumping tests before and after grouting are normally used to estimate the effectiveness of a grouting operation. Grouting for excavation dewatering can normally be done outside the excavation area and is often used to reduce the amount of water that must be handled by wells or open pumping. It is also used to construct permanent seepage cutoffs in rock foundations of hydraulic structures. Corps of Engineers publications on grouting include EM 1110-2-3506, EM 1110-2-3504, Albritton, Jackson, and Bangert (1984) (TR GL-84-13).

(b) Sheet pile cutoffs may be used in some very soft rocks. However, sheet piling cannot be driven into harder materials. The rock around the sheet pile cutoff may be fractured by the pilings during installation. This will increase the amount of flow around and beneath the cutoff wall and greatly reduce its effectiveness.

(c) Slurry walls may also be used as cutoffs in rock. However, due to the difficulty and expense of excavating a deep narrow trench in rock, slurry walls are usually limited to use in soft rocks that may be excavated with machinery also used in soils.

(d) Recent developments in mechanical rock excavators that permit excavation of deep slots in relatively strong and hard rock have resulted in increased cost-effectiveness of using diaphragm walls as effective cutoff barriers.

(e) Ground freezing may be used to control water flows in areas of brecciated rock, such as fault zones. The use of freezing is generally limited to such soil-like materials. The design, construction, and operation of ground freezing systems should be performed by an engineering firm specializing in this type of work.

Section III
Ground Control

11-8. Stability Through Excavation Planning

During the design or construction planning stages of a project that involve significant cuts in rock, it is necessary to evaluate the stability of the planned excavations. The stability of such excavations is governed by the discontinuities within the rock mass. The occurrence, position, and orientations of the prominent discontinuities at a site should be established during the exploration phase of the project. Using the information and the proposed orientations of the various cut faces to be established, vector analysis or stereonet projections may be used to determine in which parts of the excavation potentially unstable conditions may exist. If serious stability problems are anticipated, it may be possible to change the position or orientation of the structure or excavation slope to increase the stability. However, the position of the structure is usually fixed by other factors. It may not be practical to change either its position or orientation unless the stability problems created by the excavation are so severe that the cost of the necessary stabilizing measures becomes excessive. It may never be possible to delineate all discontinuities and potentially unstable areas before excavation begins. Unexpected problems will likely always be exposed as construction progresses and will have to be dealt with at that time. But performing this relatively simple and inexpensive analysis during design and planning can reduce construction costs. The costs and time delays caused by unexpected stability problems or failures during construction can be extreme. The level of effort involved in determining the stability of the excavation slopes will be governed by the scale of the project and the consequences of a failure. A very detailed stability analysis may be performed for a dam project involving very deep foundation cuts where a large failure would have a serious impact on the economics and safety of the operation. The level of effort for a building with a shallow foundation may only include a surface reconnaissance survey of any exposed rock with minimal subsurface investigations and then any unstable portions of the excavation may be dealt with during construction.

11-9. Selection of Stabilization Measures

When choosing a stabilization method, it is important that the applicable methods be compared based on their effectiveness and cost. In some cases, it may be permissible to accept the risk of failure and install monitoring equipment to give advance warning of an impending failure. Hoek and Bray (1977) gives a practical example of selecting a stabilization method from several possible alternatives.

11-10. Stabilization Methods

Remedial treatment methods for stabilizing slopes excavated in rock were briefly discussed in Chapter 8. Stabilization methods to include drainage slope configuration, reinforcement, mechanical support and shotcrete are discussed in more detail below.

a. Drainage. The least expensive method of increasing the stability of a slope is usually to drain the ground water from the fractures. This can be done by horizontal drain holes drilled into the face, vertical pumping wells behind the face, or drainage galleries within the slope. In conjunction with drainage of the ground water, surface water should be kept from entering the fractures in the slope. The ground surface behind the crest should be sloped to prevent pooling and reduce infiltration. Diversion ditches may also be constructed to collect runoff and carry it away from the slope. Diversion and collection ditches should be lined if constructed in highly permeable or moisture sensitive materials.

b. Slope configuration. Other stabilization methods involve excavating the slope to a more stable configuration. This can be done by reducing the slope angle or by benching the slope. Benching results in a reduced overall slope angle and the benches also help to protect the work area at the base of the slope from rockfall debris. If the majority of the slope is stable and only isolated blocks are known to be in danger of failing, those blocks may simply be removed to eliminate the problem. The use of controlled blasting techniques may also improve the stability of an excavated slope by providing a smoother slope face and reducing the amount of blast-induced fracturing behind the face.

c. Rock reinforcement. Rock reinforcement may be used to stabilize an excavation without changing the slope configuration and requiring excess excavation or backfill. Rock bolts or untensioned dowels are used to control near surface movements and to support small to medium sized blocks. They may be installed at random locations as they are needed or in a regular pattern where more extensive support is required. Rock anchors or tendons are usually used to control movements of larger rock masses because of their greater length and higher load capacity. One of the advantages of using reinforcement is that the excavation face may be progressively supported as the excavation is deepened. Thus, the height of slope that is left unsupported at any one time is equal to the depth of a single excavation lift or bench. After installation, rock reinforcement is also out of the way of activity in the work area and becomes a permanent part of the foundation. Rock bolts or anchors may also be installed vertically behind the excavation face prior to excavation to prevent sliding along planar discontinuities which will be exposed when the cut face is created. The effects of rock reinforcement are usually determined using limit equilibrium methods of slope analysis. Methods for determining anchorage force and depth are given in Chapter 9 on Anchorage Systems. While the methods discussed in Chapter 9 were primarily developed for calculating anchor forces applicable to gravity structures, the principles involved are also applicable to rock slopes. Additional information may be found in EM 1110-1-2907 (1980) and in the references cited in Chapter 8.

d. Mechanical support and protection methods. Mechanical support methods stabilize a rock mass by using structural members to carry the load of the unstable rock. These methods do not strengthen the rock mass. The most common type of mechanical support for foundation excavations is bracing or shoring. In rock excavations, support usually consists of steel beams placed vertically against the excavation face. In narrow excavations, such as trenches, the vertical soldier beams are held in place by horizontal struts spanning the width of the trench. In wider excavations, the soldier beams are supported by inclined struts anchored at the lower end to the floor of the excavation. Steel or timber lagging may be placed between the soldier beams where additional support is needed. One of the disadvantages of bracing and shoring is that mobility in the working area inside the excavation is hampered by the braces. A common solution to this problem is to tie the soldier beams to the rock face with tensioned rock bolts. This method utilizes the benefits of rock reinforcement while the beams spread the influence of each bolt over a large area. When only small rock falls are expected to occur, it may not be necessary to stabilize the rock. It may only be necessary to protect the work area in the excavation from the falling debris. Wire mesh pinned to the face with short dowels will prevent loose rock from falling into the excavation. The mesh may be anchored only at its upper edge. In this case, the falling debris rolls downslope beneath the mesh and falls out at the bottom of the slope. Wire mesh may be used in conjunction with rock bolts and anchors or bracing to help protect workers from debris falling between larger supports. Buttresses, gabions, and retaining walls, although commonly used for support of permanent slopes, are not normally used to support temporary foundation excavations.

e. Shotcrete. The application of shotcrete is a very common method of preventing rock falls on cut rock slopes. Shotcrete improves the interlock between blocks on the exposed rock surface. The shotcrete does not carry any load from the rock and so is more a method of reinforcement than of support. Shotcrete may also be applied over wire mesh or with fibers included for added strength and support. Shotcrete is fast and relatively easy to apply and does not interfere with workings near the rock cut. Shotcrete also aids in stabilizing rock cuts by inhibiting weathering and subsequent degradation of the rock. This is discussed further in Section IV on Protection of Sensitive Foundations.

Section IV
Protection of Sensitive Foundation Materials

11-11. General

Some rocks may weather or deteriorate very rapidly when exposed to surface conditions by excavation processes. These processes may cause a considerable decrease in the strength of the near surface materials. The processes most likely to be responsible for such damage are freeze-thaw, moisture loss or gain, or chemical alteration of mineral constituents. To preserve the strength and character of the foundation materials, they must be protected from damaging influences.

11-12. Common Materials Requiring Protection

There are several rock types that, because of their mineralogy or physical structure, must be protected to preserve their integrity as foundation materials.

a. Argillaceous rocks. Shales and other argillaceous rocks may tend to slake very rapidly when their moisture content decreases because of exposure to air. This slaking causes cracking and spalling of the surface, exposing deeper rock to the drying effects of the air. In severe cases, an upper layer of rock may be reduced to a brecciated, soil-like mass.

b. Swelling clays. Joint filling materials of montmorillonitic clays will tend to swell if their moisture content is increased. Swelling of these clays brought about by precipitation and runoff entering the joints may cause spalling or block movement perpendicular to the joints.

c. Chemically susceptible rock. Some rock types contain minerals that may chemically weather at a very rapid rate to a more stable mineral form. The feldspars in some igneous rocks and the chlorite and micas in some schists may rapidly weather to clays when exposed to air and water. This process can produce a layer of clayey, ravelling material over the surface of hard, competent rock.

d. Freeze/thaw. Most rocks are susceptible to some degree to damage from freezing. Water freezing in the pores and fractures of the rock mass may create high stresses if space is not available to accommodate the expansion of the ice. These high stresses may create new fractures or enlarge or propagate existing fractures, resulting in spalling from the exposed face.

11-13. Determination of Protection Requirements

The susceptibility of the foundation materials to rapid deterioration or frost damage should be determined during the exploration phase of a project. If possible, exposures of the materials should be examined and their condition and the length of time they have been exposed noted. If core samples are taken as part of the exploration program, their behavior as they are exposed to surface conditions is a very good indication of the sensitivity of the foundation materials to moisture loss. Samples may also be subjected to freeze-thaw and wet-dry cycles in the laboratory. The behavior of the rock at projects previously constructed in the same materials is often the best source of information available provided the construction process and schedule are similar. In this respect, the project design, construction plan, and construction schedule play important roles in determining the need for foundation protection. These determine the length of time excavated surfaces will be exposed. Climatic conditions during the exposure period will help determine the danger of damage from frost or precipitation.

11-14. Foundation Protection Methods

The first step in preventing damage to sensitive foundation materials is to plan the construction to minimize the length of time the material is exposed. Construction specifications may specify a maximum length of time a surface may be exposed without requiring a protective coating. Excavation may be stopped before reaching final grade or neat excavation lines if a surface must be left exposed for an extended period of time. This precaution is particularly wise if the material is to be left exposed over winter. The upper material that is damaged by frost or weathering is then removed when excavation is continued to final profiles and the rock can be covered more quickly with structural concrete. It may not be possible to quickly cover the foundation materials with structural concrete. In this case it is necessary to temporarily protect the foundation from deterioration. This can be done by placing a protective coating over the exposed foundation materials.

a. Shotcrete. Sprayed-on concrete, or shotcrete, is becoming perhaps the most common protective coating for sensitive foundation materials. Its popularity is due largely to the familiarity of engineers, inspectors, and construction contractors with its design and application. Shotcrete can be easily and quickly applied to almost any shape or slope surface. If correctly applied, it prevents contact of the rock with air and surface water. If ground water is seeping from the rock, weep holes should be made in the shotcrete to help prevent pressure buildup between the rock and the protective layer. Otherwise, spalling of the shotcrete will most likely occur. The shotcrete may be applied over wire mesh pinned to the rock to improve the strength of the protective layer. When used as a protective coating only, the thickness of the shotcrete will normally be 2-3 inches.

b. Lean concrete or slush grouting. Slush grouting is a general term used to describe the surface application of grout to seal and protect rock surface. The grout used is usually a thin sand cement grout. The mix is spread over the surface with brooms, shovels, and other hand tools and worked into cracks. No forms of any kind are used. Lean concrete may also be specified as a protective cover. It is similar to slush grouting in that it is placed and spread largely by hand. However, the mix has a thicker consistency and a thicker layer is usually applied. Because of the thicker application, some forming may be necessary to prevent lateral spreading. Both methods provide protection against surface water and moisture loss to the air. The use of slush grouting and lean concrete for protection are limited to horizontal surfaces and slopes of less than about 45 degrees due to the thin mixes and lack of forming.

c. Plastic sheeting. Sheets of plastic, such as polyethylene, may be spread over foundation surfaces to prevent seepage of surface moisture into the rock. This may also provide a small degree of protection from moisture loss for a short time. Sheet plastics work best on low to medium angled slopes. The plastic sheets are difficult to secure to steep slopes, and water may stand on horizontal surfaces and penetrate between sheets. The sheets can be conveniently weighted in place with wire mesh.

d. Bituminous coatings. Bituminous or asphaltic sprays may also be used as protective coatings. These sprays commonly consist of asphalt thinned with petroleum distillates. The mixture is heated to reduce its viscosity and is then sprayed onto the rock surface. These coatings are effective as temporary moisture barriers. However, they are not very durable and usually will not remain effective for more than 2 to 3 days.

e. Resin coatings. Various synthetic resins are manufactured for use as protective coatings for rock, concrete, and building stone. These products generally form a low permeability membrane when sprayed on a surface. The membrane protects the rock from air and surface water. Life expectancy, mixes, and materials vary with different manufacturers. These materials require specialized equipment and experienced personnel for application. Resin coatings may need to be removed from rock surfaces prior to placement of structural concrete to assure proper rock/concrete bond. Sources of additional information are limited due to the somewhat limited use of these coatings. Potential suppliers of these materials may include manufacturers of coatings, sealers, or resin grouts.

Section V
Excavation Mapping and Monitoring

11-15. Mapping

Geologic mapping should be an integral part of the construction inspection of a foundation excavation. This mapping should be performed by the project geologist who will prepare the Construction Foundation Report required by ER 1110-2-1801. Thorough construction mapping ensures that the final excavation surfaces are examined and so aids in the discovery of any unanticipated adverse geologic conditions. Mapping also provides a permanent record of the geologic conditions encountered during construction. Appendix B of EM 1110-1-1804, Geotechnical Investigations, and Chapter 3 of this report outline procedures for mapping open excavations.

11-16. Photography

Photographs should be taken of all excavated surfaces and construction operations. As with mapping, photographs should be taken by the person(s) responsible for preparation of the Construction Foundation Report (ER 1110-2-1801). However, project staffing may be limited such that it may be necessary to require the contractor to take the photographs. All photos must be properly labeled with date, subject, direction of view, vantage point, photographer, and any other pertinent information. Photographs of excavated surfaces should be as unobstructed as possible. Complete photographic coverage of the project is very important. Recently, videotaping has also provided benefits. This should be impressed upon the geologists and engineers responsible for construction mapping and inspection.

11-17. Construction Monitoring

Monitoring of construction procedures and progress should be performed on a regular basis by the designers in accordance with ER 1110-2-112. The schedule of design visits should be included in the Engineering Considerations and Instructions to Field Personnel. Excavation monitoring must be performed as thoroughly and frequently as possible to ensure that complete information is obtained on the as-built condition of the rock foundation. A checklist may be used that allows the inspector to give a brief description of various features of the foundation and the construction activities. An example of such a checklist is given in Appendix B of EM 1110-1-1804.