

DAMS

Dam sites are selected on the basis of topography, followed by a thorough geologic investigation. A geologic investigation should include, as a minimum—

- **Soundness.** Determine the soundness of underlying foundation beds and their ability to carry the designated load.
- **Water integrity.** Determine the degree of watertightness of the foundation beds at the dam location and the necessary measures, if any, to make the underlying geologic strata watertight.
- **Duration of water exposure.** Study the effect that prolonged exposure to water has on the foundation bedrock.
- **Potential for quake activity.** Determine the possibility of earth movement occurring at the dam site and what it takes to safeguard against such failures.
- **Availability of materials.** Investigate what natural materials are available near the site (potential quarries, sand, gravel, fill).

Generally, igneous rocks make the most satisfactory material for a dam foundation. Most igneous rocks are as strong as or stronger than concrete. However, many tuffs and agglomerates are weak. Solution cavities do not occur in igneous rocks because they are relatively insoluble; however, leakage will take place along joints, shear zones, faults, and other fissures. These can usually be sealed with cement grout.

Most metamorphic rocks have foundation characteristics similar to igneous rocks. Many schists are soft, so they are unsuitable as foundations for large, concrete dams. Marble is soluble and sometimes contains large solution cavities. As

a rule, metamorphic rocks can be treated with cement grout.

Sandstones allow seepage through pores, joints, and other fissures. The high porosity and low permeability of many sandstones make them difficult to treat with cement grout. Limestone's solubility creates large underground cavities. Generally, the strength of shale compares favorably with that of concrete; however, its elasticity is greater. Shale is normally watertight.

TUNNELS

After determining the general location and basic dimensions of a tunnel, consider geological problems before designing and constructing it. Civil engineers dealing with tunnel construction understand the need for geological data in this field, so failure due to the lack of geological information seldom occurs. However, many failures do occur because engineers improperly interpret the available geological facts.

Folded Strata

Extensive fracturing often exists along the axis of folded rock. This presents difficulties in tunneling operations. In an anticline, such fractures diverge upward; in a syncline, they diverge downward. If a tunnel is placed along the crest of a fold, the engineer can expect trouble from shattered rock. In such a case, the tunnel may have to be lined its entire length. In a syncline, an engineer could face additional trouble, even with moderate fracturing. The blocks bounded by fracture planes are like inverted keystones and are very likely to drop. When constructing tunnels in areas of folded rocks, the engineer should carefully consider the geologic structure. If a tunnel passes through horizontal beds, the engineer should encounter the same type of rock throughout the entire operation. In folded strata,

many series of rock types can be encountered. Therefore, carefully mapping geological structures in the construction area is important.

Faulted Strata

As with folded rocks, the importance of having firm, solid rock cannot be stressed enough, not only for safety and convenience in working but also for tunnel maintenance after completion. If rock is shattered by faulting, the tunnel must be lined, at least in the crushed-rock area. Also, if the fault fissure extends to the surface, it may serve as a channel for rainwater and groundwater.

Groundwater Problems

Groundwater presence is often the main trouble source in tunnel construction. If tunnel grades cannot facilitate groundwater drainage, it may be necessary to pump throughout the tunnel. Therefore, it is necessary to have accurate information before beginning tunnel construction. Apply grout or cement, when possible, to solve water problems.

BRIDGES

Geological principles also apply in bridge construction. The weight of the bridge and the loads that it supports must be carried by the underlying foundation bed. In most cases, bridges are constructed for convenience and economy, so they must be located in specified areas. Therefore, engineers cannot always choose the best site for piers and abutments. Once construction begins, the bridge location cannot be easily changed and should only be done so under exceptional circumstances.

As a rule, bridges are constructed to cross over rivers and valleys. An older riverbed or other depression (caused by glaciation or river deposits) could be completely hidden below the existing riverbed. Problems could arise if such a buried

valley is not discovered before bridge construction begins. For example, riverbeds contain many types of deposits, including large boulders. If preliminary work is not carefully done and correlated with geological principles, existing boulder deposits could be mistaken for solid bedrock.

BUILDINGS

Ground conditions at a building site may be one of three general types:

- On or near ground surface. Solid rock could exist at ground surface or so close to the surface that the foundation of the building can be placed directly on it.
- Below ground surface. Bedrock could exist below ground surface so that an economic, practical foundation can be used to support the building load.
- Far below ground surface. The nearest rock stratum could be so far below the surface that it cannot be used as a foundation bed. A building's foundation must be built on the material that forms the surface stratum.

If solid rock is present, its strength and physical properties must be determined. When the foundation consists of loose, unconsolidated sedimentary material, proper steps must be taken to solve the problem of subsidence. Structures that are supported on bedrock, directly or through piles or piers, will settle by extremely small amounts. If a foundation has been supported in unconsolidated strata, appreciable settlement can be expected.

QUARRY OPERATIONS

Natural sand and gravel are not always available, so it is sometimes necessary to produce aggregate by quarrying and processing rock. Quarrying is normally done only where other materials of

adequate quality and size cannot be obtained economically and efficiently.

Many rock types are suitable for construction, and they exist throughout the world. Therefore, the quality and durability of the rock selected depend on local conditions. The following rock types are usually easy to quarry. They are also durable and resistant to weathering.

- Granite. As a dimension stone, granite is fairly durable and has a texture and a color that are desirable for polishing. As a construction material for base courses and aggregate, it is not as desirable as some of the denser igneous rocks.
- Felsite and rhyolite. These are durable and make good aggregate for base courses. They are not suitable for concrete aggregate.
- Basalt. The dense, massive variety of basalt is excellent for crushed rock, base course, and bituminous aggregate. It is very strong and durable. Due to basalt's high compressive strength, processing it may be more difficult than processing other rocks.
- Sandstone. Few sedimentary rocks are desirable for construction due to their variable physical properties, but sandstone is generally durable. However, deposits must be evaluated individually, due to the variable nature of grains and cement present in the rock.
- Limestone. Limestone is widely used for road surfacing, in concrete, and for lime production. It is a good, all-around aggregate.
- Gneiss. Most varieties of gneiss have good strength and durability and make good road aggregate.

- Quartzite. Quartzite is hard and durable, so it is an excellent rock for construction. However, it can be difficult to quarry.
- Marble. The texture and color of marble make it desirable for dimension stone. It can also be used for base course and aggregate material.

Factors that enhance the easy removal of rock often diminish its suitability for construction. Strong, durable, unweathered rock usually serves best for embankment and fill, base and surface course material, concrete aggregate, and riprap. However, these rocks are the most difficult to quarry or excavate.

Soils continuously change. Weathering, chemical alteration, dissolution, and precipitation of components all occur as soils accumulate and adjust to their environment. Particle coatings and natural cements are added and removed. Soluble components wash downward (leach) or accumulate in surface layers by evaporation. Plants take root and grow as soil profiles develop. These changes tend to become more pronounced with increasing age of the soil deposit. These possible alterations to the sediment may affect its utility in construction. The soils of natural geological deposits are commonly used as construction materials.

Section IV. Applied Military Geology

The science and applied art of geology is an important component of military planning and operations. Today, computers, satellites, geographic information systems, geographic positioning systems, and similar technology have catapulted the art and science of geology as an everyday tool for military commanders and engineers.

MILITARY GEOGRAPHIC INTELLIGENCE

The purpose of geographic intelligence is to obtain data about terrain and climate. Commanders use the information to make sound decisions and soldiers use it to execute their missions. In planning an operation, commanders and their staff analyze the effects that terrain and climatic conditions will have on the activities of friendly and enemy forces. Knowledge of how geology controls and influences terrain is helpful for classifying and analyzing terrain and terrain effects. When provided with adequate geographic and geologic intelligence, commanders are able to exploit the advantages of the terrain and avoid or minimize its unfavorable aspects. Data on soil movement, the presence of hard rock, and the kind and distribution of vegetation is needed when considering concealment and cover, cross-country travel, and field fortifications. Strategic intelligence studies prepared by Department of Defense agencies provide detailed geographic and terrain information (*Table 2-2*) useful for compiling and analyzing geographic intelligence.

Maps and Terrain Models

Maps are a basic source of terrain information. Geologic maps show the distribution, age, and characteristics of geologic units. They may also contain cross sections that show the subsurface occurrence of rock and soil. Maps may have text explaining physical properties; engineering properties; and other information on natural construction materials, rock formations, and groundwater resources. Soil maps are commonly presented under an agricultural classification but may be used for engineering purposes after they have been converted to engineering nomenclature.

A terrain model is a three-dimensional graphic representation of an area showing the conformation of the ground to scale. Computer-generated images have recently been developed that display two-dimensional form images in three-dimensional form for viewing from any angle.

Remote Imagery

Aerial and ground photography and remote imagery furnish information that is not readily available or immediately apparent by direct ground or aerial observation. Examples are infrared photography and side-looking radar. Imagery permanently preserves information so that it is available for later study. Photographs normally depict more recent terrain features than available maps.

Terrain Classification

Land forms are the physical expression of the land surface. For terrain intelligence purposes, major land forms are arbitrarily described on the basis of local relief (the difference in elevation between land forms in a given area).

GEOLOGY IN RESOLVING MILITARY PROBLEMS

To apply geology in solving military problems, personnel must first consider geologic techniques and uses and then determine how to acquire the needed information. Commanders can use geology in three ways—geologic and topographic map interpretation, photo interpretation, and ground reconnaissance.

Maps

Combination topographic and geologic maps can tell commanders and engineers what the ground looks like. Map information should be made available early in operation planning. The success of many

Table 2-2. Reports for geographic/terrain intelligence

Report Title	Report Application
Imagery interpretation	Planning combat and support operations Planning recon activities Supporting requests for terrain intelligence Analyzing areas of operations Planning terrain studies
Terrain study on soils	Supporting communications planning Executing movement, maneuver operations Planning combat operations (construction of landing strips, maintenance of culverts) Selecting avenues of approach
Terrain study on rocks	Planning movement, maneuver operations Planning combat operations (construction, maintenance, and destruction of roads, bridges, culverts, and defensive installations) Selecting avenues of approach
Terrain study on water resources	Selecting locations of and routes to water points Planning combat operations (street crossing, bridging) Supporting logistics planning
Terrain study on drainage	Supporting communications planning Planning combat operations (constructing roads, fortifications, and fjords) Supporting river crossings and cross-country movement
Terrain study on surface configuration	Supporting communications planning Planning observation posts and recon activity Planning tactical operations and executing tactical objectives Planning barrier and denial operations Planning artillery support
Terrain study on the state of the ground	Planning movement, maneuver operations Planning ADM activity Planning combat operations (constructing, maintaining, and repairing roads, fjords, landing strips, and fortifications) Planning logistics support
Terrain study on construction suitability	Planning combat operations (constructing fortifications, landing strips, camouflage, obstacles, and a CP's supply installations) Selecting construction supply-point locations
Terrain study on coasts and landing beaches	Planning amphibious operations (preparing and removing obstacles and fortifications) Planning recon activity Planning port construction
Terrain study on cross-country movement	Planning and executing maneuver, movement operations Planning logistics support Planning barrier and denial operations Planning engineer combat operations
Terrain study on airborne landing areas	Planning area-clearing support Planning recon activity Planning combat operations (constructing and repairing landing strips) Selecting helicopter landing zones

military operations depends on the speed of required advance construction. Speed, in turn, depends on completely understanding the needs and adequately planning to meet those needs in a particular area. Topographic maps are important

sources of information on slope and land forms. One problem in using a topographic map is that some relief or roughness may be hidden between the contour lines. Generally, the larger the interval between contour lines and the smaller the

scale of the map, the more the relief is hidden. Conversely, the smaller the contour intervals and the larger the scale of the map, the less the relief is hidden.

Photographic Interpretation

Many principles that make a geologic map useful for estimating the terrain situation also apply to the usefulness of aerial photographs. The interpreter's skill is very important. Without a professional photo interpretation and the knowledge of geologic process and forces, a great deal of information may be overlooked. In preparing terrain intelligence, aerial photographs alone will not provide enough information. Geologic maps must also be available. Aerial photographs are completely reliable for preparing tactical terrain intelligence. However, the usefulness of aerial photographs varies with the scale of the report being prepared.

Reconnaissance

Interpretation of the land for military purposes can be accomplished by studying maps and can be even more accurate by adding photographs. Using maps or photographs is highly effective, but it cannot compare in accuracy to actual ground observation. In a tactical situation, such as when attacking a defended position, the knowledge of the terrain behind the position is vital for planning the next move. Terrain may be different on the side that cannot be seen. Generally, the difference is expressed in the geology of the slope that can be observed. By combining ground observation and reconnaissance by a trained observer (geologist) with aerial and map interpretation, the commander can plan ahead. Reconnaissance of secure territory can be used to an even greater advantage when developing the area of occupation or advancement.

REMOTE IMAGERY

The major kinds of remotely sensed imagery are photography, radar, and multispectral or digital scanner imagery. Since the 1930s, various worldwide agencies have acquired a large amount of remote imagery. The quality, scale, and nature of the coverage vary considerably because new techniques and equipment are being developed rapidly. Remote imagery can be—

- Generated quickly in a specified time.
- Displayed accurately.
- Produced in a useful and storable format.
- Produced in volume (*Table 2-3*).

High-altitude aircraft and spacecraft imagery are desirable for regional geologic mapping and delineating major structural features. Stereo coverage of low-, medium-, and high-altitude photography is used for detailed geologic mapping of rock units, structure, soil type, groundwater sources, and geologic hazards such as slope failure, sinkholes, fracturing zones, and flooding.

FIELD DATA COLLECTION

Field data collection is necessary to—

- Supplement existing information obtained from published and unpublished literature.
- Obtain site-specific, detailed information that describes the local geology.

Mission constraints, such as time, resources, weather, and political climate, limit the amount of field investigation that can be conducted. The following methods and procedures, which were designed primarily for civilian peacetime

Table 2-3. Sources of remote imagery

Procurement Platform	Imagery Format	Scale	Coverage	Source Agency
Low-, medium-, and high-altitude aircraft	Black and white or color stereo pairs of aerial photos of high resolution	1:12,000 1:125,000	Limited worldwide (low altitude, 1942 to present; high altitude, 1965 to present)	USGS, EROS data center, Sioux Falls, SD
Low-, medium-, and high-altitude aircraft	Black and white, color, color IR, black and white IR, thermal IR, SLAR, multiband imagery (reproductions of imagery are available to all US military organizations and US government agencies)	1:1,000 1:100,000	Partial to full coverage of most foreign countries from late 1930s to present	DIA, ATTN: DC-6C2, Washington, DC 20301
Low-, medium-, and high-altitude aircraft	Black and white, color IR	Main scales: 1:20,000 1:40,000 Black and white: 1:20,000 to 1:120,000	Black and white: 80% of US Color IR: Partial US	ASCS, Aerial Photo Field Office, PO Box 30010, Salt Lake City, UT 84130
Unmanned satellites ERTS LANDSAT 1-5 MSS— Band 4: green (0.5-0.6 m) Band 5: red (0.7-0.8 m) Band 6: near IR (0.7-0.8 m) Band 7: near IR (0.8-1.0 m)	Black and white, color composite (IR), color composition generation, 7 and 9—track computer—compatible tapes (800 and 1,600 bpi)	1:250,000 1:3,369,000	Worldwide coverage, complete earth's surface coverage every 18 days, 1972 to present; every 9 days, 1975 to present	EROS data center
Manned spacecraft Skylab with S-190A multispectral camera and S-190B system, single lens (earth terrain camera)	S-190A: black and white, black and white IR, color IR, high resolution color S-190B: black and white, color, stereo pairs	S-190A: 1:1,250,000 1:2,850,000 S-190B: 1:125,000 1:950,000	Limited worldwide coverage	EROS data center

projects, serve as a guide for the kinds of geologic information that can be obtained in field investigation.

All available geologic information (literature, geologic and topographic maps, remote sensing imagery, boring logs, and seismic data relative to the general area of the project) should be collected, identified, and incorporated into

the preliminary study for the project. This preliminary study should be completed before field investigations begin. A preliminary study allows those assigned to the project to become familiar with some of the engineering problems that they may encounter. Geologic information available in published and unpublished sources must be supplemented by data

that is gathered in field investigations. Some of the most reliable methods available for field investigation are boring, exploration excavation, and geophysical exploration.

Boring

Borings are required to characterize the basic geologic materials at a project. They are broadly classified as disturbed, undisturbed, and core. Borings are occasionally made for purposes that do not require the recovery of samples, and they are frequently used for more than one purpose. Therefore, it is important to have a complete log of every boring, even if there is not an immediate use for some of the information. Initial exploration phases should concentrate on providing overall information about the site.

Exploration Excavation

Test pits and trenches can be constructed quickly and economically using bulldozers, backhoes, draglines, or ditching machines. Depths are normally less than 30 feet. Side excavations may require shoring, if personnel must work in the excavated areas. Exploratory tunnels allow for detailed examination of the composition and the geometry of rock structures such as joints, fractures, faults, and shear zones. Tunnels are helpful in defining the extent of the marginal strength of rock or adverse rock structures that surface mapping and boring information provide.

Geophysical Exploration

Geophysical exploration consists of making indirect measurements from the earth's surface or in boreholes to obtain subsurface information. Boreholes or other subsurface explorations are needed for reference and control when using geophysical methods. Geophysical explorations are appropriate for rapidly locating and correlating geologic features such as

stratigraphy, lithology, discontinuities, structure, and groundwater.

EQUIPMENT FOR FIELD DATA COLLECTION

The type of equipment needed on a field trip depends on the type of survey being conducted. The following items are always required:

- **Hammer.** This is usually a geologic hammer, and it is used to break or dig rock and soil and to prepare samples for laboratory examination. A hammer is also useful for determining the strength and resistance of the rock and the toughness of the grains.
- **Hand lens.** A hand lens is a small magnifying glass, usually 10X power. It is used to examine individual mineral grains of rock for identification, shape, and size.
- **Dilute hydrochloric (HCl) acid.** One part concentrated HCl acid to four parts water is used to determine carbonate rocks. Dilute acid is preferred because the degree of its reaction with different substances is seen more easily.
- **Brunton compass.** One of the most important pieces of equipment to the field geologist is the Brunton compass. This instrument is an ordinary magnetic compass with folding open sights, a mirror, and a rotating dial graduated in degrees or mils. In some cases, the dial is numbered to 360 degrees, while in others, the dial may be graduated in 90-degree quadrants. A compass helps measure dips, slopes, strikes, and directions of rock formations.
- **Base map.** A base map is essential in all types of field work except when the plane-table-and-alidade method is used.

GEOLOGICAL SURVEYING

The instruments and methods of geological surveying are numerous and varied. Instruments used on a particular project depend on the scale, time, detail, and accuracy required.

Pace-and-Compass Method

The pace-and-compass method is probably the least-accurate procedure used. The survey is conducted by pacing the distance to be measured and determining the angle of direction with the compass. The field geologist records elevations on a topographic map, when it is available. When a topographic map or a good equivalent is unavailable, an aneroid barometer or some type of accurate altimeter is used to record elevations.

Plane-Table-and-Alidade Method

When accurate horizontal and vertical measurements are required, the plane-table-and-alidade method is used. The equipment consists of a stadia rod, a tripod, a plane table, and an alidade. Sheets of heavy paper are placed on the plane table to record station readings. After recording the stations, the geologist places formation contacts, faults, and other map symbols on the paper. This information can later be transferred to a finished map. The alidade is a precision instrument consisting of a flat base that can easily be moved on the plane table. The straight edge, along the side of the flat base and parallel to the line of sight, is used to plot directions on the base map. The alidade also consists of a telescopic portion with a lens that contains one vertical hair and three horizontal hairs (stadia hairs). The vertical hair is used to align the stadia rod with the alidade. The horizontal hairs are used to read the distance to the rod. Vertical elevations are determined from the stadia distance and the vertical angle of the points in question.

Brunton-Compass-and-Aerial-Photo Method

A Brunton compass and a vertical aerial photo provide a rapid, accurate method for geological surveys. The aerial photo is used in place of a base map. Contact, dips and strikes, faults, and other features may be plotted directly on the aerial photo or on a clear acetate overlay. Detailed notes of the geological features must be kept in a separate field notebook. If topographic maps are available, they will supplement the aerial photo and eliminate the need for an aneroid barometer. A topographic map may be used for the base map and to plot control for horizontal displacements.

Plane-Table-, Mosaic-, and-Alidade Method

A mosaic of aerial photos may be used with a plane table and an alidade, thus eliminating the base map. This procedure is used to eliminate the rod holder and to accelerate the mapping. By using a plane table and an alidade as a base, horizontal distance does not have to be measured; and the surveyor can compute vertical elevation. The surveyor—

- Reads the angle of variation from the horizontal distance.
- Scales the distance from the map.
- Finds the difference by trigonometric calculations.

This method is faster than the normal plane-table method, but it is not as accurate.

Photogeology Method

Photogeology is the fastest and least-expensive method of geological surveying. However, a certain amount of accuracy and detail is sacrificed. This type of survey is normally used for reconnaissance of

large areas. When a geologic map is constructed from aerial-photo analysis alone, it shows only major structural

trends. After a preliminary office investigation, a geologist may go to the field and determine detailed geology of particular areas.