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GEOLOGIC FACTORS IN DAM AND RESERVOIR PLANNING

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ABSTRACT

The planning of dam and reservoir sites must include careful consideration of the geologic environment. Knowledge of the principal elements of this environment — topography, hydrology, and geology — contributes to the success of a project. Various conditions in bedrock and unconsolidated deposits, such as discontinuities and the presence of shale or cavernous limestone, lead to problems in dam and reservoir construction and maintenance. Availability of construction materials, the effect of the project on the area's mineral resources, and the balance between site quality and budget, are economic aspects of dam and reservoir planning for which geologic considerations are important.

INTRODUCTION

As man strives to improve his environment, the development of a dam and reservoir is frequently planned to serve one or more purposes, such as flood control, water supply, and water-based recreation. Dams and reservoirs must be built on the surface of the earth and, in many instances, with natural earth materials. Therefore, one of the first steps in planning such a project is the evaluation of geologic conditions to determine the suitability of the site for the proposed project. This note provides a brief discussion of the principal factors that must be considered in evaluating the geologic setting of dam and reservoir projects in Illinois.

GEOLOGIC FACTORS

The geologic conditions that exist at and in the vicinity of every proposed dam and reservoir should be known and understood by those responsible for its planning and design. The principal elements that must be considered are topography, hydrology, hydrogeology, and geology.

Topography

In the geological sense, topography is the configuration of the land surface, and it includes the location, size, and shape of such physical features as hills, ridges, valleys, streams, and lakes. Topographic maps show these features.

As a short dam is most economical to construct, the site selected should be at a point where the valley is narrow. The valley upstream should have sides high enough to contain the planned reservoir without necessitating construction of small dams or dikes in low divides. The reservoir sides should be relatively steep so that a minimal area would be exposed by the lowering of the water surface during normal operation of the reservoir. However, if swimming is one of the water-based activities being planned, there must be an adequate depth of water in the vicinity of gently sloping shores. Topographic relief and steepness of the slopes in the entire watershed influence the rate at which water runs off the surface of the land, which is an important factor in both dam and spillway design. They are important also because they influence the potential rate of erosion, the probable amount of siltation to be expected, and the adaptability of the project to certain uses.

If the proposed project involves the maintenance of wildlife, the topography of the site must insure a sufficient depth and supply of water throughout the dry season. The reservoir should be planned to avoid large areas of water less than 4 feet deep because aquatic plants become a nuisance in such shallow water, and water less than 2 feet deep becomes choked with marsh plants. The latter condition also creates a mosquito problem. A biologist should be consulted on matters influencing the biological environment.

Inspection of a topographic map coupled with reconnaissance of the land often is sufficient to establish the general topographic suitability of a proposed dam and reservoir site. This is the first and easiest step in determining the feasibility of a proposed project.

Hydrology and Hydrogeology

Hydrology is the science relating to the water of the earth, its distribution and its phenomena. To be successful, a dam and reservoir project must have an adequate and continuous supply of water suitable for the

intended uses of the reservoir. Hydrologic information and investigation will be required in varying degree, depending upon the size of the project. The annual rainfall, the ratio of watershed area to reservoir area, and the volume of stream flow at all seasons of the year must be known. The study of hydrogeology to determine whether ground water would contribute to the reservoir or whether the reservoir would lose water to the ground-water system is also essential. The reservoir capacity and maximum and minimum reservoir yield also must be known so that commitments for water will not exceed the quantity of water available.

The behavior of streams in the project watershed is important. In areas where vegetation is sparse, occasional short periods of high-intensity rainfall may produce flash floods with high peak discharges capable of collecting a great quantity of soil debris and transporting it into the reservoir. Run-off from large storms and flood flows must be estimated or measured, as this information is necessary for the proper design of the dam and for the determination of spillway capacity.

Accumulation of sediment may soon reduce the usefulness of a reservoir and may ultimately destroy its capacity. In Illinois, silt derived from surficial deposits of loess becomes trapped in reservoirs; for this reason, a percentage of reservoir capacity is allotted to sediment storage. Sediment control is probably one of the most difficult of soil conservation problems and requires the cooperation of all land users in the drainage area tributary to the reservoir. Where siltation is severe, it may be desirable or even necessary to consider two reservoirs in series, the upstream one designed to function as a sedimentation basin to prevent the rapid accumulation of silt in the downstream reservoir.

Turbidity of the proposed reservoir is another phase of hydrology that should be considered. Too much turbidity, or suspended sediment, makes a reservoir unsuitable for the propagation of desired aquatic life or for swimming. Pollution of all kinds must also be considered because it can be detrimental to the recreational or industrial usefulness of the reservoir. Sources and kinds of pollution should be ascertained and control or regulatory measures included in the planning.

While hydrology is properly an important factor in the evaluation of a dam and reservoir project, the study of hydrologic factors is the work of the specialist in hydrology, especially in the planning of large projects.

Geology

It has been said that construction of a dam and reservoir causes more interference with natural conditions than does any other civil engineering operation. Knowledge of the geological situation is essential as a basis for sound engineering, especially in the investigation of dam and reservoir sites, for an error in geological interpretation or the failure to discover some relatively minor geologic detail may be costly and sometimes hazardous.

To judge properly the feasibility of a proposed dam and reservoir project, it is necessary to know the kind, distribution, and succession of the rocks and other geologic units in the project area, for the stability of the dam and the water-holding ability of the reservoir are directly related to them. Facets of geology that must be evaluated in determining the suitability of a project site include (1) the attitudes of the units—that is, whether they are flat lying or inclined; (2) the depth and extent of weathering; (3) the presence and condition of discontinuities, such as open or closed joints, faults, or solution channels; (4) the presence of layers of sand or silt and of old soil zones. The engineering properties of the geologic units—for example, their strength or ability to bear the weight of the dam, their reaction to alternate wetting and drying, and their permeability—are directly related to the kind of rock or unconsolidated material involved and, therefore, to the geology.

Although the details of Illinois geology are complex, most of the geologic units exposed at the surface belong to two general classes, sedimentary rocks and unconsolidated glacial and alluvial, or stream-laid, deposits. Under confined conditions nearly all sedimentary rocks and many unconsolidated glacial and alluvial deposits, if sound and unweathered, have more than enough strength to support the weight of a dam.

Damsite and reservoir problems generally arise from conditions associated with discontinuities in the bedrock and unconsolidated deposits rather than from an inherent deficiency of the material. The characteristics of the sedimentary rocks and some conditions that are commonly the sources of problems in dam and reservoir construction and maintenance are described briefly below. If the conditions are known and understood, problems can generally be avoided by appropriate design or by remedial treatment.

Sources of Problems in Areas of Sedimentary Rocks

Discontinuities—The principal discontinuities in sedimentary rocks are bedding planes, joints, faults, and solution openings.

Bedding planes mark the upper and lower boundaries of each layer of sediment and are present in all sedimentary rocks. They may be closely or widely spaced, tightly closed or open, fresh or weathered. Thin layers of clay or soft shale may occur along a bedding plane, and if the rocks and bedding planes are inclined, these layers can become sliding surfaces that create stability problems.

Joints are fractures that cut across the bedding planes and tend to cut the rock units into blocks. Joints may be vertical or inclined, and it is common for more than one set of subparallel joints to be present. Joints may be tightly closed or open, and they offer avenues along which surface weathering, including solution, can penetrate the rock mass.

Faults are ruptures in the rock mass along which there has been differential movement of the rocks on opposite sides of the rupture. Severe

fracturing of the rock commonly accompanies faulting, and a fault may be marked by a zone of fracturing rather than by a single fracture. Faults and the fracturing that accompanies them also afford avenues by which surface weathering and solution activity can attack the rock. Fault zones present a possible escape route for the reservoir water, and faults also indicate, in varying degree, the hazard of continued or repeated movement. Faults in the foundation and abutment rocks at a damsite and in a reservoir area introduce problems of bearing strength, stability, and watertightness and, therefore, sites that contain them should be avoided. Stable dams can be designed for faulted foundations, but the cost of the necessary remedial treatment may be prohibitive.

Solution cavities, as the name implies, are openings developed in the more soluble rocks by the solvent action of water. They are troublesome discontinuities that frequently occur in limestone and related carbonate rocks.

Openings made by underground mining are man-made discontinuities. Underground mining often is accompanied or followed by subsidence of the overlying rocks, producing fractures which may reach the surface. If a proposed dam and reservoir site is located over a mined-out area, very careful consideration should be given to the possibility of leakage and of whether the site will remain stable under the new conditions resulting from construction of the project. Trouble is more likely in areas where mining was shallow than where it was deep, and in connection with large projects than with small. In some instances a damsite can be stabilized by placing concrete in the portion of the old mine openings that lie directly beneath it, but such corrective treatment is expensive. Small drift mines in hillsides, for which no records were kept and whose locations are not known, can be the cause of unexpected reservoir leakage in some areas of Illinois.

Shale—The term shale denotes a fine-grained sedimentary rock composed largely of clay and silt and having a laminated or thinly layered structure. The term is also used to include the nonlaminated clayey rocks, and many shale deposits are composed of both laminated and nonlaminated units. Shales vary widely in their properties, the variations being closely related to such factors as clay mineralogy, arrangement of mineral particles, environment of deposition, and post-depositional history of the deposit. Some shales provide excellent foundations for dams, as they are rocks of low permeability and may have strengths comparable to those of good concrete. Sound shales present few damsite problems and a minimum of reservoir problems.

Some shales are subject to deformation under the application or removal of load, but this problem is more critical for large dams than for small. Bedding planes, vertical or horizontal joints, and faults, along any of which there may be thin veneers of soft clay, are examples of discontinuities that reduce the resistance of shale to sliding and shear. If open, these discontinuities may also act as avenues of leakage. Perhaps the most common problem with shale as foundation rock is its rapid deterioration when subjected to alternate wetting and drying while exposed during construction. This can generally be prevented by coating the surface to seal out moisture, but coating adds to the cost of construction.

Sandstone—Sandstones are rocks composed of sand grains held together by some sort of cementing agent. While sandstones generally have sufficient strength to support the weight of a dam, crumbly and poorly cemented ones may permit sufficient seepage to be troublesome; this, however, can generally be overcome by remedial treatment. Sandstones are frequently interstratified with shale, and seepage through the sandstone beds may lubricate the shale-sandstone contact and reduce its resistance to sliding. The principal problems with sandstones stem from the fact that they generally are cut by many joints. It is not unusual for joint blocks of sandstone to creep down the side of a valley, in which case deep stripping of the abutment material may be necessary. Open joints in the abutments below the level of the reservoir may be grouted by injecting a cement slurry, that is, a mixture of cement and water. If the joints are wide, they may be backfilled with concrete to prevent excessive leakage. Jointed or permeable sandstone beneath a dam foundation must be grouted to reduce undesirable uplift effects. In Illinois, sandstone usually makes a satisfactory foundation and abutment rock, as undesirable conditions commonly can be corrected with a reasonable amount of foundation treatment.

Limestone—Limestones and related carbonate rocks vary widely in their suitability as foundations for dams and reservoirs. Thick-bedded and undeformed limestones that are relatively free of solution cavities make excellent dam foundations and reservoir basins; but thin-bedded, deformed, and cavernous limestones present serious problems that may be so extensive as to make corrective measures impracticable. The major problems with limestones result from their solubility. Solubility in the sense of changes that may occur during or after construction is of little or no importance, but the effects of solution activity that operated through past geologic periods are of tremendous importance and must be determined in evaluating the suitability of a dam and reservoir site.

Limestones and related carbonate rocks involved in a dam and reservoir project almost invariably contain solution cavities. They may be thin cavities along bedding planes and joints, or large caverns. They may be open or water-filled conduits, or be partially or completely filled with sediment. The size, form, abundance, depth, and complexity of the interconnected system of cavities depend upon the details of the local geologic structure and the presence of interstratified layers of insoluble or impermeable materials. Sinkholes are depressions in the land surface in a limestone region that are connected with underground passages formed by solution. The presence of sinkholes in an area is a warning that cavernous limestones are present and that extreme caution must be exercised in selecting dam and reservoir sites.

With proper remedial treatment a stable dam can be designed and constructed on cavernous limestone, but the cost may be very high. Small cavities in the foundation and abutments generally can be sealed by first washing them out with air and water under high pressure and then grouting them with a slurry of cement or other suitable material. Large cavities may have to be mined out and backfilled with concrete. Reservoirs should be reasonably watertight, and cavernous limestone in the reservoir basin may provide many avenues for the escape of water. The problem of excessive

leakage from the reservoir may prove to be insurmountable because it is not practicable to search out and seal off all solution channels in a cavernous limestone basin. Project sites that contain cavernous limestone are generally abandoned in favor of sites that offer better foundation conditions because of the cost and difficulty of accomplishing effective remedial treatment.

Large areas in extreme southern Illinois have been affected by faulting, and many of the faults involve limestones that are known to be cavernous. The combination of faulting and cavernous limestones makes it very difficult to find satisfactory sites for dams and reservoirs in this area.

Sources of Problems in Areas of Unconsolidated Deposits

More than three-fourths of the surface of Illinois has been altered by glaciation. Some of the results of glaciation are buried bedrock valleys, changed drainage systems, valleys deeply filled with glacial and recent alluvium, and extensive deposits of clayey till, loess or windblown silt, outwash sands and gravels, and water-deposited silts. In glacial terranes, conditions and earth materials vary within short distances, necessitating detailed observation of surface features and careful subsurface investigation of proposed dam and reservoir sites. Knowledge of the preglacial, glacial, and postglacial history of a locality is helpful in the preliminary evaluation of sites in that it permits a general prediction of the kinds of conditions that may be encountered.

Clayey till is widespread in Illinois and makes excellent foundations and abutments for dams of moderate size. However, deposits of permeable sand and gravel commonly occur within and between deposits of till, providing avenues of possible leakage. Such permeable deposits in the abutments or beneath the foundation are generally amenable to treatment, but this increases construction costs.

A common damsite situation is one in which the abutments consist of glacial till — a heterogeneous mixture of sand, silt, clay, and pebbles — and the valley is filled with glacial and recent alluvium. It is important to ascertain in considerable detail the character, size, shape, and location of the lenses and strata that make up the valley fill in order to make adequate provisions for a foundation that will be stable under the projected load and for the negation of the effects of percolating water and hydrostatic pressure.

Deposits of silt frequently are the cause of stability problems at dam and reservoir sites in glacial and alluvial terranes. Silt particles are smaller than fine sand grains and larger than clay particles, and they lack the property of cohesiveness, or sticking together. When deposits of silt become water-logged, they lose strength and are easily deformed under load. Silt deposits are common in the glacial and recent alluvium that

fills many valleys. In some valleys the fill may be more than a hundred feet thick and consist in large part of soft, silty material that has undergone very little consolidation. Proper design can insure stability of a dam founded on such soft materials, but the character of the deposits must be ascertained before the design can be made. It is not uncommon for such a valley to contain a greater thickness of fill than might be assumed from surface evidence.

Loess (wind-blown silt) forms many surface deposits in Illinois. Problems of bank stability may develop if deposits of this material are exposed along the shoreline of a reservoir, as they are susceptible to erosion. Loess deposits are also a source of silt that can be picked up by surface wash and carried into the reservoir.

Knowledge of the presence of buried glacial valleys and the nature of their fill is important, for under some conditions they can be avenues of leakage from a reservoir. A large preglacial bedrock valley may be filled with pervious sand and gravel overlain by clayey till, with present-day streams occupying valleys cut into the pervious material. Undoubtedly a stable dam could be built in such a valley, but it is not likely that the reservoir would retain water. If a portion of a former glacial valley now filled with pervious material is present in the reservoir walls below the proposed water level, a serious leakage problem is possible.

The presence of peat or of old soil zones between deposits of glacial material can cause problems involving stability and seepage, but these can generally be overcome by remedial treatment. In a sense, old soil zones, peat beds, and layers and lenses of sand or silt are discontinuities in unconsolidated deposits. The contact of glacial deposits with bedrock is frequently marked by a zone of coarse rubble, and adequate provision must be made to insure stability and to prevent the escape of water through it.

The foregoing illustrates the nature and variety of conditions that may occur at dam and reservoir sites involving unconsolidated deposits. These conditions may occur singly or in any combination, and the seriousness of the potential problems must be appraised for each project site.

ECONOMIC ASPECTS OF DAM AND RESERVOIR EVALUATION

While a full discussion of all the economic aspects of dam and reservoir evaluation is beyond the scope of this note, three elements that are at once economic and geologic should be considered by those responsible for the planning. These are the availability of suitable construction materials, the effect of the proposed project on any developed or undeveloped mineral deposits, and the relationship between the requirements of the project site and the funds available. The last of these is largely economic but relies heavily upon preliminary geologic evaluation.

Availability of Construction Materials

The distance that construction materials must be hauled appreciably affects the cost of a project. For this reason suitable construction materials should be available near the project. Durable stone to protect exposed slopes, crushed stone for concrete aggregate, granular materials for the pervious filters, and impervious material for the embankment are required in some degree for all earth dams. Clayey till makes an excellent embankment material and is widely available. Weathered loess also may be used if better material is not available. Organic soil, watery silt, and peat must be discarded. The locations of potential deposits of suitable construction materials should be noted in the preliminary phase of damsite investigation. If there is a question of the suitability or availability of construction materials, potential deposits should be explored and tested during the detailed investigation of the damsite. In Illinois, materials suitable for construction are usually available near the damsite.

Effect of Project on Mineral Industries

Another economic-geologic element that is important in the consideration of a proposed dam and reservoir project is the effect the project might have on existing or potential installations of the extractive mineral industries, such as oil wells, mines, gravel pits, or quarries. The project may flood a quarry, a gravel pit, or a mine, making continued operation of the installation impossible. It may cover all or part of an oil field, forcing abandonment of producing wells. The impact of such an occurrence on the economy of the area and of the state must be weighed carefully against the benefits to be derived from the dam and reservoir project. If the net effect is adverse, it may be desirable to delay the project until such time as the natural resources have been depleted and the installations shut down.

On the other hand, oil wells or coal mines may be located in the reservoir area in such positions that drainage from them may adversely affect the quality of the reservoir water. This problem must also be considered and regulatory measures included in the planning.

The presence in the reservoir area of mineral resource reserves that may be recoverable in the future presents another problem. Such reserves should not be rendered unrecoverable by the project and thereby lost to the economy. Conversely, development of a project in an area could be of material assistance in hastening the development of nearby natural resources.

Balance Between Site Quality and Budget

If a dam and reservoir project is to be built, the anticipated benefits, of course, should exceed the estimated cost. Among the many considerations in determining the benefit-to-cost ratio are the estimated cost of

foundation preparation, of remedial treatment of the foundation and abutments, and the contingency that costly problems of stability or leakage may develop during or after construction and require additional treatment. At nearly all sites unexpected foundation or reservoir conditions are encountered that require special treatment, and it is customary to provide for this in the budget. It is always prudent and generally necessary to select a project site whose foundation and reservoir problems can be handled within the framework of the expected construction and maintenance budget. That is to say, site quality and budget should be in balance. In many instances, sites with costly foundation and/or reservoir problems can be eliminated by evaluation of the geologic conditions early in the consideration of the proposed project.

CONCLUDING STATEMENT

Evaluation of the geologic environment is an important early step in the consideration of a proposed dam and reservoir project. Assistance in the selection of a suitable project site is one of the most useful services provided by the geologist. If possible, more than one site should be evaluated so that the best site can be selected for the project. In many instances, the Illinois State Geological Survey can provide from information already available a general idea of the geologic conditions at proposed sites in Illinois. In such a preliminary evaluation, facts and problems can be pointed out that may eliminate from consideration the obviously unsuitable sites and focus attention on the sites worthy of detailed investigation.

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