Siltstone and claystone foundations at the Bath County hydroelectric pumped storage project

Fondations sur des grès fins et des argilolithes des ouvrages hydroélectriques d'emmagasinement par pompage de Bath County

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SYNOPSIS: At the Bath County Hydroelectric Pumped Storage Project, several changes occurred during construction as a direct result of low bedding shear strength in the siltstone and claystone bedrock. Although all major structures were designed using appropriate bedding shear strength, site excavation produced several surprises that required design changes during construction.

This paper presents an overview of the main project features, the geology of the site, bedding shear strengths, design criteria and design solutions that consider the weak bedding plane strength.

PROJECT DESCRIPTION

The Bath County Pumped-Storage Project is located in Bath County, Virginia, about 70 kilometers northeast of Covington. The project, when completed, will have a total installed capacity of 2,100 MW and will be the world's largest pumped-storage project.

Lower Reservoir. The lower reservoir will be formed by constructing a 45 meter high embankment dam containing about 3 million cubic meters of fill across Back Creek (Fig. 1). The Lower Dam cross section includes a central core protected by filters and supported by compacted earth and rockfill.

The powerhouse abuts the right bank of the lower reservoir approximately one mile upstream of the dam. Each of the six units, when in the generating mode, will have a rated capacity of 350 MW at a head of 385 meters.

Upper Reservoir. The upper reservoir will be impounded by a 140 meter high embankment dam containing about 13 million cubic meters of fill. The Upper Dam includes a central core protected by filters and supported by compacted earth and rockfill. Releases to the power tunnels will be from an intake structure located just upstream of the dam on the left abutment.

Water will be conveyed between the upper and lower reservoirs in three 8.7 meter diameter concrete-lined, power tunnels. From the intake gate shafts, each power tunnel extends about 1130 meters to a 300 meter vertical flow shaft, and then continues about 1030 meters to a bifurcation into two 5.5 meter diameter concrete and steel-lined penstocks.

Status of Construction. After a two year delay, full scale construction resumed in May of 1982. The revised schedule will place the first two pumping-generating units on line in the spring of 1985.

GEOLOGY AND PHYSIOGRAPHY

The dominant land forms in the project area are subparallel northeast trending ridges and valleys typical of the Appalachian Valley and Ridge physiographic province. The ridges are underlain or capped by comparatively resistant sedimentary rocks, while the valleys have evolved along weaker, less resistant rock units. For example, the valley of Back Creek, in which the lower reservoir is situated, has been eroded along the strike of a predominantly shaley formation.

The foundations of all project features contain sedimentary rocks of Devonian age (Fig. 2). The lower reservoir, lower dam, powerhouse, spillway and the lower part of the power tunnels are founded on or situated in the Brallier Formation. The upper reservoir, upper dam, intakes, surge tanks, and upper portion of the power tunnels involve rocks of the Chemung Formation. The rocks are compaction sediments that have been indurated by overburden loads and tectonic forces. For the most part, shales and claystones in the rock sequence slake and tend to disintegrate upon freeze-thaw and wetting-drying cycles.

The Brallier Formation, which underlies the lower reservoir in the Back Creek Valley, consists of thinly interbedded siltstone, sandstone and claystone. Medium hard, dense, thin-bedded siltstone is the predominant rock of the formation. Siliceously cemented, hard and rather thinly bedded sandstone, and dense, medium soft, thinly bedded claystone form the interbeds of the formation. Across most of the valley, as seen in the dam foundation, strata are severely folded into acute anticlines and synclines (typical chevron-type folds) striking parallel to the valley. Tectonic joints are normal to bedding planes and closely spaced. They are closed or infilled with calcite at shallow depths. Stress relief joints are quite prominent and parallel the strike of Back Creek valley.

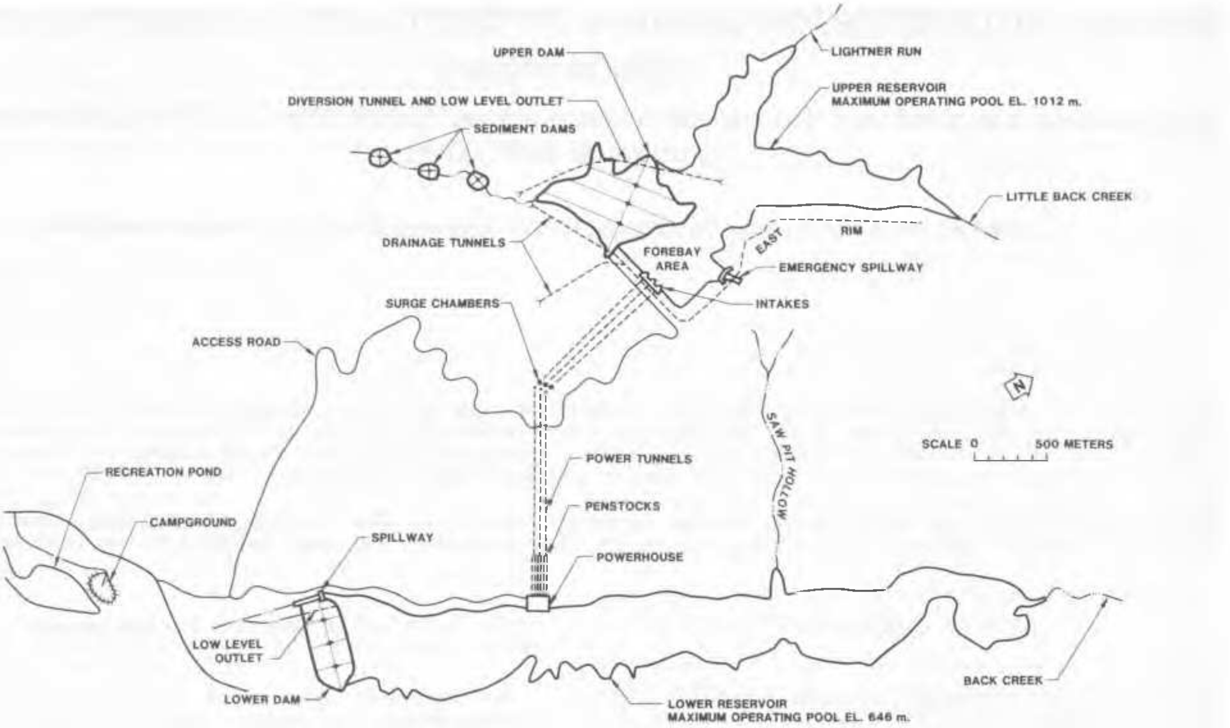

Fig. 1 BATH COUNTY PROJECT PLAN

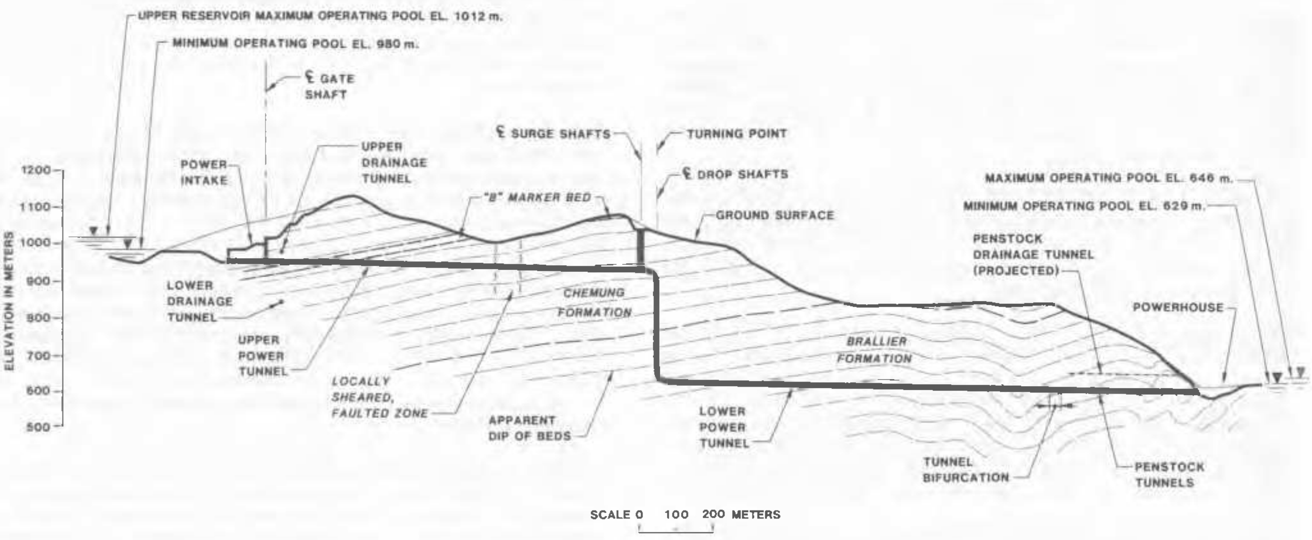

Fig. 2 GEOLOGIC SECTION ALONG POWER TUNNEL ROUTE

The upper reservoir and its dam are underlain by the thick and relatively impermeable Chemung Formation. Its dense interbedded sandstone, siltstone and shale units possess adequate strength to form the foundation for the upper dam.

The mountain tops in the upper reservoir area are capped by the Catskill Formation. This is predominantly a sequence of silty, fine-grained to conglomeratic sandstones with siltstone and claystone interbeds. Three distinct marker beds, identified by drilling, confirm stratigraphic continuity over a wide area, leading to the conclusion that no major geologic faults exist that could affect the watertightness of the upper reservoir.

SEISMIC EXPOSURE

Studies of the earthquake history and seismotectonic relationships indicated that the level of seismic exposure is low and intensity is moderate. However, it is probable that project facilities will be exposed to earthquakes originating in the Southern Appalachian seismic zone. Accordingly, allowance was made for earthquake in the design of embankments and structures. The designs were made with a conservatively chosen 0.10 seismic coefficient in pseudostatic analysis. Dynamic finite element analyses of the dams using a peak bedrock acceleration of 0.17 g were also performed.

PROBLEMS RELATED TO LOW BEDDING SHEAR STRENGTH

Direct shear tests on clays taken from exposures at the base of cliffs indicated a residual angle of internal friction (Ø') of 17°-23°. Although all project features were designed for low bedding shear strength, a number of problems occurred during construction which were directly related to bedding plane joints and/or shears.

Upper Dam Foundation. Since the earliest project investigations, attention had been drawn to the geologic structure of the upper dam foundation and its effect on stability. Interbedded Chemung sandstone and siltstone/shale layers dip at about 10 degrees from the left abutment into Little Back Creek (Fig. 3). Because of a regional joint set that strikes almost parallel to the valley, the rock surface exposed by the core trench is steplike.

Geologic and topographic evidence suggest that rock blocks have slid into the valley as the creek eroded its course. Such evidence includes the presence of broad benches of unweathered rock below steep cliffs of weathered rock and the occurrence of clays on bedding planes at the base of the cliffs. In a number of locations, deeply weathered, near-vertical joints containing breccia and silt were also found at the base of the cliffs. These features suggest that the fresh rock benches were exposed as the weathered blocks of rock slid along clay seams. The steep cliffs were not evident during site exploration because of a thick mantle of talus and slope wash deposits that accumulated at their base.

Special treatment details for the core foundation of the upper dam were developed after exposure of the foundation during construction. Excavation of the core trench resulted in a ragged, step-like surface caused by marked bedrock stratification and jointing normal to bedding as shown on Figs. 4 and 5. The varying thickness and competence of the different bedrock units resulted in steps ranging in height from 0.1 to over 4 meters.

On the left abutment, foundation shaping was required to remove unacceptable overhangs. Minor overhangs were tolerated, if less than 0.15 meters, if the overhang was not more than 3-5 meters long and if the bed thickness was less than 2 meters. More competent, thicker sandstone ledges, with more pronounced overhangs were shaped by presplitting. However, the presence of locally occurring clay seams along bedding planes, or weak clay shales at the base of some higher ledges, necessitated stabilization prior to presplitting by rock-bolting to stable rock beneath (Fig. 4).

On the right abutment, the irregular surface of the stepped foundation was more easily remedied by the use of slush grout, select impervious fill and a modest quantity of dental concrete (Fig. 5).

Sharp topographic reentrants on the left abutment created an adversely sloping foundation surface immediately downstream of the core. This condition exposed foundation bedding joints along which fines could conceivably move. A two-stage filter system was placed over foundation surfaces to prevent potential movement of foundation fines into the downstream shell (Fig. 6).

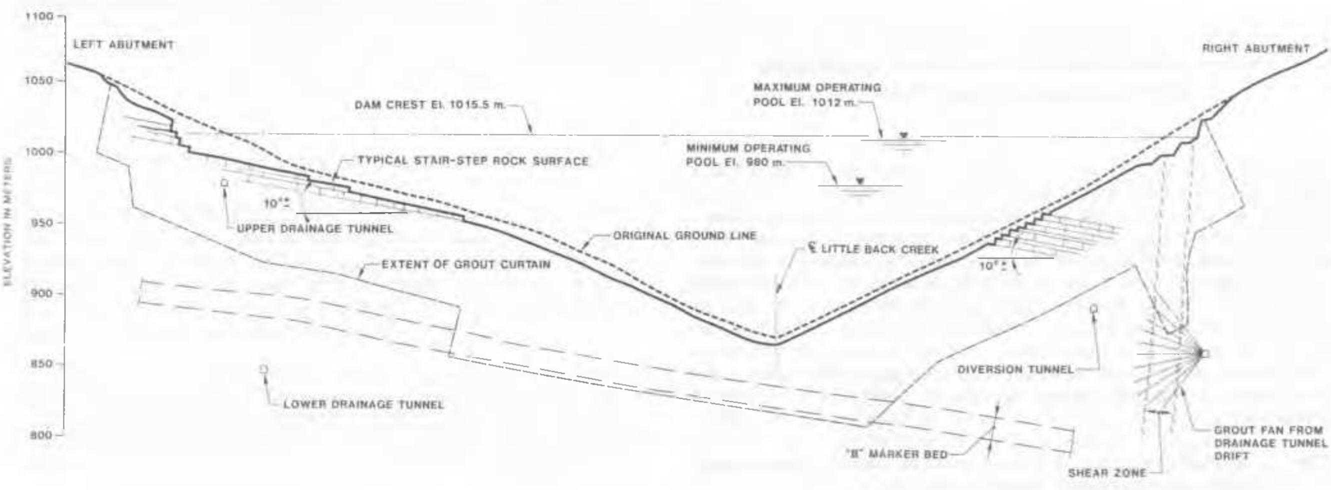

Fig. 3 UPPER DAM CROSS VALLEY PROFILE

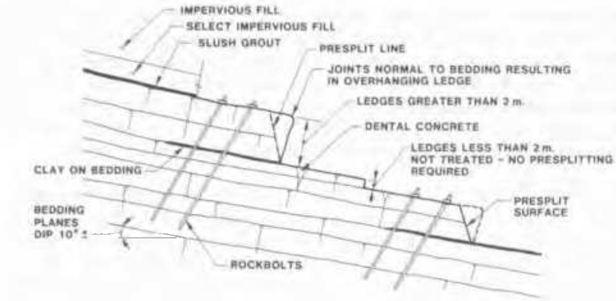

Fig. 4 UPPER DAM LEFT ABUTMENT CORE FOUNDATION TREATMENT

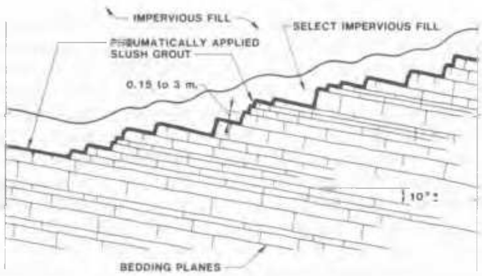

Fig. 5 UPPER DAM RIGHT ABUTMENT CORE FOUNDATION TREATMENT

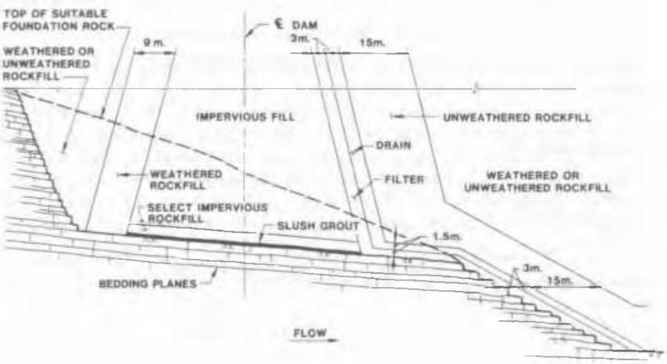

Fig. 6 UPPER DAM LEFT ABUTMENT TREATMENT AT TOPOGRAPHIC REENTRANT

Spillway Foundation. The spillway for the Lower Dam is located on the right abutment and on a topographic nose which projects into the valley. Flat-lying, thin bedded sandstones and siltstones are exposed in a nearby steep cliff. Subsurface exploration indicated an anticlinal structure upslope of the spillway ogee. Because unfavorable geologic conditions with respect to stability were suspected in the headworks foundation, a deep anchorage system with prestressed tendons was included in the original design.

The excavation for the approach wall and ogee structure proceeded routinely below the access road with geologic conditions much as expected from interpretation of drill hole data.

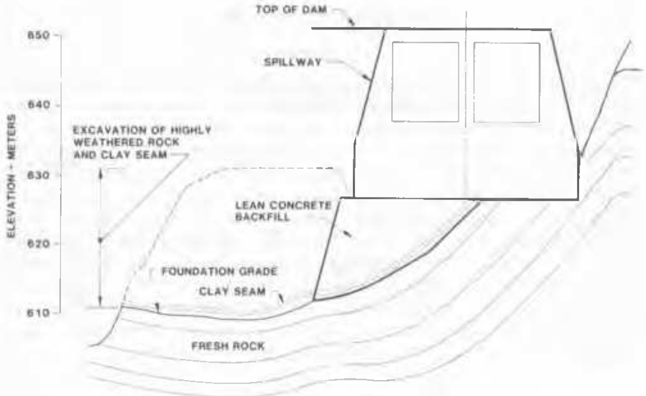

Fig. 7 LOWER DAM SPILLWAY FOUNDATION OVEREXCAVATION

However, upon reaching about 6 meters above the valley floor, a striking difference was apparent in the rock sequence. As shown on Fig. 7, a flat-lying fresh rock ledge was found to be overlain by highly fractured, deeply weathered rock with a clay seam separating the two rock masses. Investigations also indicated that a clay seam extended beneath the spillway ogee. The approximate location and geometry of the clay seam were defined, using the results of geologic mapping, test pits, and drill core logs.

Stability analysis of the rock mass indicated inadequate safety with the construction condition being the most serious. The solution was to excavate the poor quality rock and clay seam, and to backfill with lean concrete.

REFERENCES

1. Third Annual USCOLD Lecture, The Bath County Hydroelectric Pumped-Storage Project, May 1983.

2. Project correspondence and reports, 1977-1983.