WATER OPERATION AND MAINTENANCE BULLETIN

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UNITED STATES DEPARTMENT OF THE INTERIOR
Bureau of Reclamation

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For further information about the *Water Operation and Maintenance Bulletin* or to receive a copy of the index, contact:

Jerry Fischer, Managing Editor
Bureau of Reclamation
Inspections and Emergency Management Group, Code D-8470
PO Box 25007, Denver CO 80225
Telephone: (303) 445-2748
FAX: (303) 445-6381
Email: jfischer@do.usbr.gov

Cover photograph: *Cutoff wall excavation equipment.*

UNITED STATES DEPARTMENT OF THE INTERIOR **Bureau of Reclamation**

WATER OPERATION AND MAINTENANCE BULLETIN
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DESIGN OF SOIL-CEMENT-BENTONITE CUTOFF WALL FOR TWIN BUTTES DAM

by Elizabeth A. Dinneen, P.E.[1] *and Matthew Sheskier, P.E.*[2]

Introduction

One of the deepest and largest soil-cement-bentonite (S-C-B) cutoff walls is being constructed at the upstream toe of Twin Buttes Dam near San Angelo, Texas, to remediate dam safety deficiencies. The wall, excavated using slurry trench construction methods, will be 4 miles long, 1.4 million square feet, and up to 100 feet deep. The S-C-B backfill is a combination of onsite soil (gravel, sand, and clay), bentonite, and a small amount of cement. The trench will be excavated using panel construction techniques and the backfill placed using more traditional concrete diaphragm wall construction (tremie) procedures.

The cutoff wall is needed because significant seepage is occurring through the dam foundation, particularly at higher reservoir levels. This seepage generates high pressures at the downstream toe, increasing the probability of dam failure by embankment instability and piping.

Various options were evaluated to obtain an economical cutoff wall meeting the design criteria—a positive seepage cutoff capable of withstanding large head differentials acting across the cutoff wall. Several types of wall backfill materials were evaluated during the final design phase, including plastic-concrete (P-C), cement-bentonite (C-B), soil-bentonite (S-B), S-B with a vertical geomembrane, and S-C-B. Special design criteria and quality control were required because of limited experience with S-C-B backfill. Wall quality will be verified using core drilling, *in-situ* permeability and geophysics of the backfill after placement, along with rigorous inspection and quality assurance/quality control (QA/QC) requirements. It is anticipated that there will be some difficulty in trench excavation to required depths due to the existence of highly cemented alluvial materials (up to 15,000 pounds per square inch [lb/in^2] compressive strength) in the foundation.

Construction of the cutoff wall began in July 1996 with a 1,200-foot test section which was substantially completed in December 1996. The remainder of the cutoff wall and civil works required to integrate the cutoff wall into the existing dam are expected to be completed in 1999.

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[1] Team Leader, Bureau of Reclamation, Technical Service Center, Geotechnical Engineering Group, Denver, Colorado 80225.

[2] Assistant Resident Engineer, Bureau of Reclamation, Twin Buttes Field Office, San Angelo, Texas 76904.

Project Background

Twin Buttes Dam is located about 6 miles southwest of San Angelo, Texas, and was constructed by the Bureau of Reclamation (Reclamation) in 1960-63. The dam is 8.2 miles in length and extends across three streams—South Concho River, Middle Concho River, and Spring Creek (figure 1). The reservoir provides municipal water for the city of San Angelo and water for irrigation, flood control storage, recreation, and fish and wildlife benefits. The dam is an earthfill embankment with a maximum structural height of 134 feet and a crest elevation of 1991 feet. The water impounded by Twin Buttes Dam forms two pools (Middle and South Concho pools) which are connected through a high ridge by an equalizing channel. The reservoir capacity at top of active conservation (EL 1940.2) is 186,210 acre-feet and has a capacity of 1,035,000 acre-feet at EL 1985 (original maximum water surface).

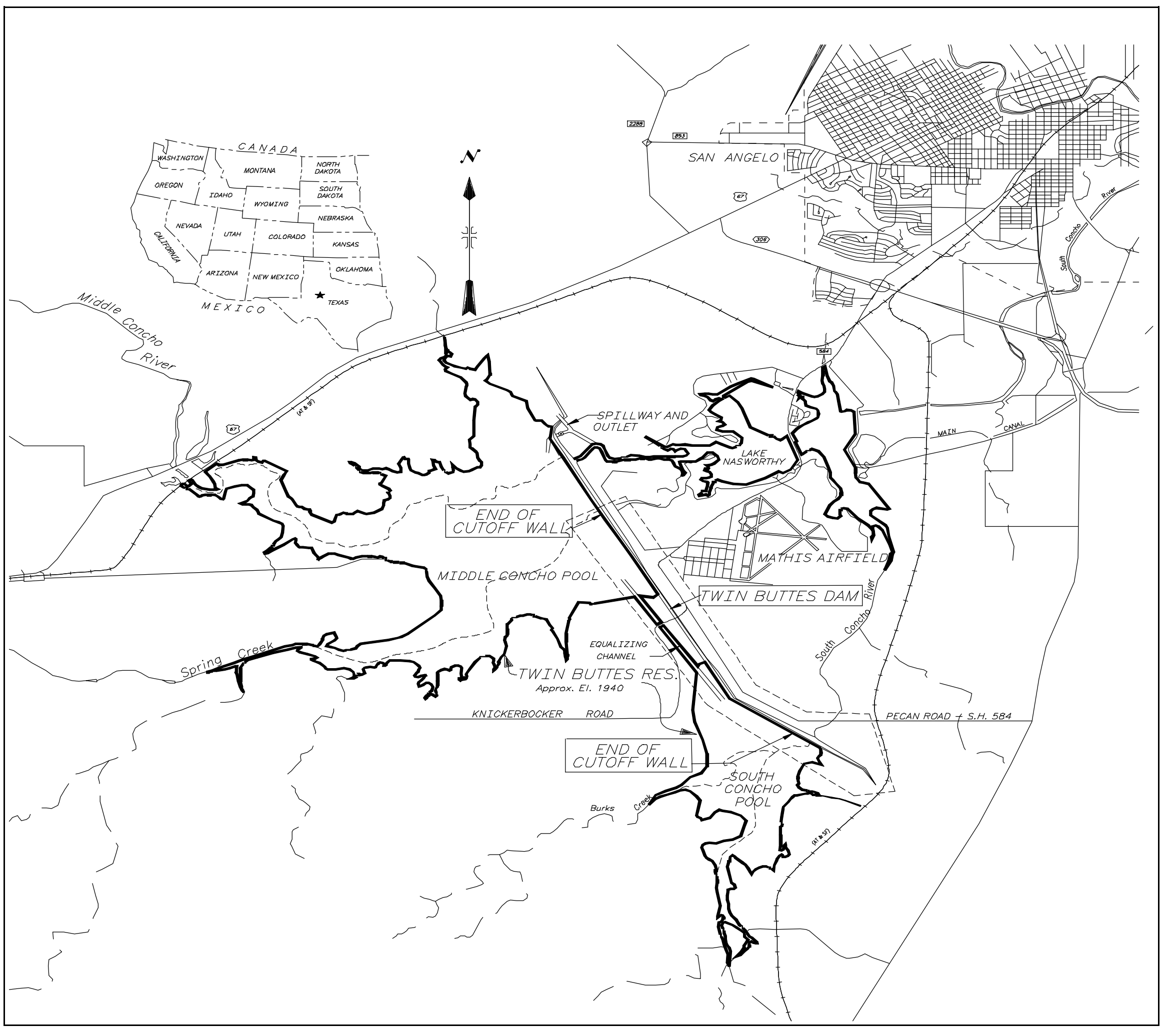

Figure 1.—Twin Buttes Dam and Reservoir - plan view.

The dam was constructed without a positive cutoff trench to bedrock in the middle 4 miles of the dam. In this area, an alluvial gravel deposit, overlain by 10 to 50 feet of clay, underlies the dam and extends from the reservoir downstream beneath the dam. The cutoff trench was not constructed in this area partly because of the depth to bedrock (averaging 60 feet and as much as 100 feet) and because the clay deposit was felt to be sufficiently impermeable and would adequately cap the more pervious gravels. However, outcroppings of the alluvium are exposed throughout the reservoir, and, during construction, borrow areas were excavated within 150 feet of the upstream toe of the dam, further exposing the alluvial gravel layer. The combination of the lack of a positive cutoff trench in this central reach and exposure of the alluvial gravels to the reservoir has led to significant seepage underneath the dam.

Geotechnical analyses concluded that substantial, uncontrolled seepage occurring in the foundation of the dam could lead to a failure of the dam from high uplift pressures leading to embankment instability or from blowout at the downstream toe and subsequent piping of the foundation. These types of failures could result in a sudden, catastrophic release of the reservoir.

The city of San Angelo is located downstream of the dam and has a population of approximately 90,000 people. A Threat to Life Study determined that the total population at risk impacted by a dam failure by embankment instability and piping is about 22,600 people, and the estimated loss of life is about 2,850 people. Property damage to San Angelo and the surrounding area would exceed $660 million. Failure of Twin Buttes Dam would eliminate the primary municipal water supply for San Angelo and expose the area to frequent flooding and irrigation losses.

In 1991, a reservoir restriction of EL 1930 was placed on Twin Buttes Reservoir and is in effect until remedial measures to address the seepage deficiency have occurred. The restriction allows safe passage of up to the 50-year flood event.

Geologic Conditions

The foundation of Twin Buttes Dam in the 4-mile reach of this study consists of a fine-grained clay deposit which overlies Pleistocene alluvial gravels. Beneath the alluvial gravel is bedrock, which is a Permian interbedded sandstone and shale.

The upper fine-grained deposit is mostly lean clay rich in calcite and referred to as "caliche." The caliche varies in thickness from about 10 feet to 60 feet and is derived from windblown and fluvial deposits. The caliche is locally cemented to various degrees. The caliche has an average of 85 percent fines (passing the No. 200 sieve) and 15 percent sand.

Underlying the caliche deposit are Quaternary alluvial deposits of Pleistocene age consisting mostly of coarse-grained soils (predominantly clayey gravel). The alluvial deposit, which varies in thickness from 0 to 65 feet, is highly variable in gradation and cementation. The gravel, cobble, and boulder fragments in the alluvial deposits are predominantly limestone with some chert and quartzite. The alluvial deposit is cemented to various degrees by calcium carbonate with material having compressive strengths up 15,000 lb/in^2. The measured permeability of the alluvium has ranged from 0 to 500,000 feet per year.

The bedrock beneath the alluvial deposits consists of flat-lying shale and sandstone of the Permian San Angelo Formation. The material is relatively impermeable, with the upper 1 to 3 feet being weathered, but the underlying rock is sound. The project is located in a seismic inactive area (Zone 0, Uniform Building Code Seismic Zone Map).

The 1994 investigations (Reclamation, 1995) proved the geology of this area is extremely variable and unpredictable, even over very short vertical or horizontal distances. Highly cemented gravel often grades abruptly to uncemented sands and open-work gravels or clays within only 10 to 20 feet, while other beds are continuous for over 2,000 feet. The degree of cementation and permeability in the alluvium is very difficult to predict or model accurately and was an important consideration in the selection of a cutoff wall as the final design alternative.

Seepage History

Seepage was first noted in the downstream streambank of the South Concho River in 1964, 1 year after construction was completed and when the South Concho pool was at EL 1926. From 1965 to 1971, seepage conditions remained relatively stable. During this period, the South Concho pool elevation varied between 1915 and 1925 feet, and the Middle Concho pool elevation varied between 1878 and 1886 feet. In August 1971, major inflow raised both pools to EL 1927. Seepage began to pond at the downstream toe between dam stations 278+00 and 299+00 (2,100 linear feet) and extended 1,500 feet downstream from the toe of the dam. In October 1974, the reservoir rose to EL 1941. A rapid expansion of the water table occurred in the area with no positive cutoff trench. Seepage surfaced up to 2,000 feet downstream of the dam, and ground water was within 2 feet of the ground at the Municipal Airport located 1 mile downstream.

Previous Remedial Measures

Grouting

Between 1976 and 1980, three attempts were made to grout the alluvial material in the portion of the foundation where there was no cutoff trench. The grouting had to be discontinued because of severe caving during drilling of the grout holes in areas of loose, uncemented sands and gravels. As subsequent higher reservoir operations demonstrated, the grouting did not effectively reduce downstream piezometric pressures.

Relief Wells and Downstream Drainage System

In 1984, 61 relief wells were installed in two critical areas along the downstream toe of the dam. The relief wells were intended to reduce uplift pressures on the embankment and were not expected to control the effects of seepage beyond the vicinity of the downstream toe of the embankment. A drainage system was also installed to protect the same areas from becoming saturated and inaccessible.

In 1986-87, and again in 1990, the reservoir rose to EL 1936, allowing evaluation of the relief well system. Piezometric levels downstream of the dam indicated pressures were still high and that failure due to high uplift pressures could occur at reservoir levels as low as EL 1945, which is about 5 feet higher than active conservation but 46 feet below the crest of the embankment. Total seepage from Twin Buttes Reservoir has been estimated at 60 cubic feet per second or more. The analyses concluded that the system of wells was not adequate to control foundation water pressures and would not function as intended. This evaluation concluded that additional remediation would be required.

Dam Safety Alternatives Investigated

As part of Reclamation's Safety of Dams Program, a Corrective Action Alternatives (CAA) Study was performed (Harza, 1994). Structural and nonstructural alternatives were considered to mitigate the seepage. Nonstructural alternatives, such as reservoir restrictions, early warning systems, and no action, were deemed unacceptable because of inadequate protection of the public or loss of project benefits (Reclamation, 1994).

Structural alternatives considered included three concepts for mitigating the seepage deficiency. The first concept included alternatives that would "cut off" the seepage—a cutoff wall, an upstream blanket, and grouting. The second concept would control seepage by providing drainage features downstream of the dam. Alternatives included seepage berm, deep drainage trench, sand and wick drains, and relief wells. The third concept was to eliminate reservoir storage by breaching the dam.

Geologic and geotechnical information gathered by Reclamation after the CAA Study raised concerns over piping of the foundation materials, channelized seepage paths, and variability of the foundation material, including permeability. These concerns are significant enough that downstream drainage alternatives were considered to have an unacceptably high risk of not adequately mitigating the problems and, therefore, were not technically adequate alternatives for correcting the seepage deficiency.

Blanketing the upstream areas would not ensure complete cutoff of seepage. The ineffectiveness of the previous grouting programs to control seepage led to the conclusion that further grouting would not be effective.

Breaching the dam was identified as a technically viable alternative, but it was not economically viable because of the high cost associated with lost project benefits.

Of the structural and nonstructural alternatives considered, constructing a cutoff wall and breaching the dam were identified as the only technically viable alternatives (Reclamation, February 1994). Based on economic evaluation of these two options, the cutoff wall was selected as the most economical (Reclamation, June 1994). The study recommended a cutoff wall be constructed in the areas where a positive cutoff trench was not constructed during original dam construction. The type of backfill to be used in the cutoff wall would be further evaluated during final design.

Cutoff Wall Design

Wall Design Criteria

Design requirements for the cutoff wall included low permeability, resistance to gradients, cost, and constructibility (compatibility with standard excavation techniques and common placement procedures).

To serve as an impermeable barrier, the backfill is required to have a permeability equal to or less than 1×10^{-6} centimeters per second. To achieve the necessary "positive" cutoff of seepage, not only does the wall need to be sufficiently keyed into impervious bedrock formation, but it also needs to be designed and constructed to withstanding the loading conditions to which it may be subjected over the course of its design life. The potential for high hydraulic gradients exists at Twin Buttes Dam during extreme flood situations where reservoir levels rise to the crest of the dam. For cutoff wall design calculations, it was assumed reservoir levels at the crest of the dam (EL 1991) and that the cutoff wall could be effective enough to result in pre-dam construction ground-water levels downstream, which were at EL 1871. Based on these ground-water elevations, there is the potential for a head differential of up to 120 feet acting across the wall, which equates to approximately 50 lb/in^2 for a 2½-foot-wide wall.

If the high hydraulic gradients due to high reservoir levels develop, piping of the backfill into the surrounding pervious and open-work alluvial materials in the foundation at Twin Buttes Dam could occur.

Backfill Alternatives

Several backfill alternatives were evaluated for use at Twin Buttes Dam on the basis of the above design criteria. The backfills evaluated included P-C, C-B, S-B, S-B with an internal (vertical) geomembrane, and S-C-B.

The type of backfill selected carries significant cost implications when multiplied over 4 miles and 1.4 million square feet of cutoff wall. S-B material is generally the least expensive, typically utilizing local soil (excavation spoil or other locally available soil material) and employing simple backfilling techniques; C-B cost is mid-range, with higher costs due in part to cement content and considerable waste; and concrete (including P-C) is the most expensive because of the relatively high costs of the concrete aggregate, quantities of cementitious materials typically associated with such products, and the expensive batching, handling, and placement procedures.

Plastic Concrete—P-C backfill was considered technically feasible as far as its constructibility (compatible with conventional panel excavation methods and tremie placement is common) and its resistance to high gradients (easily controllable strength characteristics); however, P-C backfill was not considered economically feasible. The cost is considerably higher than the other alternatives considered due in part to the limited sources for concrete aggregate within 30 miles of San Angelo which would substantially increase the cost.

Cement-Bentonite—Although C-B backfill costs are more reasonable than P-C and it could be produced to resist the high gradients by adjusting its cement content, it was not considered to be technically feasible with regard to its constructibility. Since trench excavation was expected to be very slow at times in the cemented alluvium, it was a concern that C-B slurry would set up before the wall excavation was completed. This would result in delays and additional costs due to re-excavation of the C-B backfill as well as the potential for “flash” set and entrapment of equipment. Also, there was a concern that a requirement for C-B would preclude the use of hydromills, as C-B was not considered to be entirely compatible with hydromill excavation due to the common usage and requirement for desanding of the slurry. Additionally, a replacement (or displacement) method of construction for using C-B backfill following excavation with bentonite slurry was not considered practical because of the similarities in specific gravity of bentonite slurry and C-B slurry/ backfill.

Soil-Bentonite—The low cost of S-B made this backfill a very attractive alternative. However, there were technical concerns with S-B backfill in narrow trenches, such as the potential for hydraulic fracturing and blowout of backfill. Settlement of S-B backfill could cause high stresses to develop which result in arching across the trench leading to horizontal and piping of the backfill into the surrounding pervious alluvial materials.

To reduce the potential for hydraulic fracturing and blowout failure, the width of the cutoff wall can be increased, but there are practical limits to which the trench width can be increased. Typical trench widths that common slurry trench excavation equipment (backhoes, clamshells, and hydromills) are capable of excavating in a single pass of the equipment range from 2 to 5 feet.

The width of an S-B wall required to prevent blowout failure was estimated using the relationship published by the Corps of Engineers (COE) (1986) and Xanthakos (1979):

$$width = \frac{differential\ head}{blowout\ gradient} \times safety\ factor$$

The wall at Twin Buttes Dam, assuming a recommended safety factor of 3 and a recommended hydraulic (blowout) gradient of 30, would need to be 12 feet wide to prevent blowout. Excavation of a 5-foot-wide trench at Twin Buttes Dam was deemed to be at best a time-consuming, expensive proposition, if not beyond the practical capabilities of commonly available equipment due to the depths and expected difficulty of excavation.

Another method of reducing blowout potential, recommended by Reclamation (Reclamation, 1991), is to apply dam filter criteria to the backfill. Several S-B backfill mixes were designed to meet Reclamation filter criteria (Reclamation, 1994) and Reclamation criteria for S-B backfill (Reclamation, 1991) against actual gradations of open-work gravel materials documented during construction of the original dam. Blowout gradient tests (Xanthakos, 1981) were then performed on the S-B backfill mixes to confirm the applicability of these engineered backfills to the loading and foundation conditions at Twin Buttes Dam. These tests determine the gradient at which the S-B backfill will fail (i.e., hydraulic fractures or pipes into foundation material). High increases in flow occurred at gradients as low as 4 and up to 32, which results in a safety factor of 0.2 to 1.3 for a 5-foot-wide wall.

Because of the potential for high differential heads, unknowns in the amount and location of open-work alluvial materials in the foundation, trench width construction limitations, and results of the blowout tests, it was decided that if S-B backfill were to be considered further, additional safeguards would be necessary to mitigate the potential for hydraulic fracturing and blowout. The additional safeguards investigated, as discussed below, included installation of a vertical geomembrane in the trench and increasing the strength of the S-B backfill with the use of cement.

Vertical Geomembrane Barrier**—**A vertical geomembrane installed in the trench after excavation followed by backfilling with S-B would provide an additional line of defense against hydraulic fracturing and/or blowout of the backfill into the foundation open-work gravels. A vertical geomembrane barrier in an approximate 15-mile-long trench (drainage sand was used as backfill) was successfully used at another Reclamation project, Reach 11 Dikes, near Phoenix, Arizona. However, concerns with use of the geomembrane, such as difficult installation, backfill drag down forces, puncturing/rupturing of geomembrane, and ensuring adequate keying into bedrock, could not be adequately resolved, and this alternative was eliminated from consideration.

Soil-Cement-Bentonite Backfill**—**The final alternative investigated was adding a small percentage of cement to S-B backfill material. Use of soil-cement-backfill was used on the

Sacramento River Levees, a COE project in Sacramento, California, and during modification to Sam Rayburn Dam, another COE project in Jasper, Texas. The addition of cement provides the needed strength to resist hydraulic fracturing and/or blowout of the backfill into the foundation open-work alluvial materials. Also, though not a specific design criteria, the bentonite in the mix results in a more ductile wall, capable of withstanding greater strains and resists cracking. The cutoff wall backfill for Twin Buttes Dam would be required to have a minimum compressive strength of 100 lb/in^2 at 28 days or twice the potential 120 feet of head differential.

Based on evaluation of available construction equipment, excavation rates, cost, and resolution of the blowout issue, it was determined that the optimum wall width was 2½ feet.

The S-C-B backfill placed in the trench would need to be proportioned so that the mixture resists segregation and flows readily. Laboratory mixture proportion studies were performed at Reclamation's Denver Laboratory to provide a starting point for the contractor. Several different mixtures were proportioned with cementitious content ranging from 4 to 10 percent (cement or cement plus pozzolan by dry mass of soil "aggregate") mixed with prehydrated, 4 to 5 percent bentonite-water slurry. Results indicated that the trial mix proportions would start with 6 percent (± 2 percent), by dry weight, cement or cement plus pozzolan and 1 percent (± 0.5 percent), by dry weight, bentonite (resulting from use of bentonite slurry).

Use of S-C-B backfill raises some concerns not normally associated with S-B backfill but, more usually, with P-C backfill, such as batching, segregation, and placement methods; workability; QA/QC; in-place strengths and permeabilities; uniformity of construction; and horizontal joints.

Solutions to the concerns of using S-C-B backfill were addressed by the following specification requirements:

(1) Wall construction was to consist of interconnected vertical panels with excavated panel lengths based on contractor's capability to continuously batch and place a sufficient quantity of S-C-B backfill which would completely fill the panel prior to the backfill setting up (to eliminate horizontal joints).

(2) Required soil materials in backfill to meet a specified gradation to allow for consistency in batching. The material was a reasonably well graded mixture of gravel, sand, and fines (minus No. 200 sieve) with a maximum size of 1½ inches and 10 to 20 percent fines (for QA/QC, strength and permeability, batching/segregation/placement, and uniformity).

(3) Required contractor to design the proportioning of the materials based on target requirements and advance testing to result in a workable mix, while allowing the contractor the option to replace a portion of the cementitious material with pozzolan. Modifications to the contractor's mix could only be made after justification through testing (for QA/QC, workability, and uniformity).

(4) Required use of a continuous-mixing plant capable of accurately proportioning the various ingredients to produce a uniform mixture within the specified limits (for QA/QC, strength/permeability, batching, and uniformity).

(5) Required backfill to be hauled in trucks equipped with agitators (for segregation, workability, and uniformity).

(6) Required backfill slump of 7 to 10 inches (for workability and placement).

(7) Required placement of backfill from bottom of panel to top through sufficient numbers of minimum 10-inch-diameter tremie pipes such that backfill does not flow more than 7½ feet horizontally from a tremie (for segregation, placement, strength/permeability, and uniformity).

(8) Required bentonite slurry in the panel, immediately prior to backfill placement, to have a density less than 75 pounds per cubic foot; a sand content less than 5 percent; and a viscosity, as measured by the Marsh funnel, to be less than 45 seconds (for placement, strength/permeability, and uniformity).

(9) Required rigorous QA/QC program consisting of meticulous record keeping of batching operations; casting of a minimum of 6- by 12-inch backfill samples of each panel placed for unit weight determination, compressive strength testing, and permeability testing; continuous coring of selected wall panels and water testing of cored holes; test pits at selected locations for visual confirmation of wall quality; and piezometers installed immediately upstream and downstream of the cutoff wall.

Cutoff Wall Location

Trench stability, construction costs, and construction access were considered in selecting the wall alignment. To minimize costs associated with integrating the cutoff wall into the existing embankment, the wall was located as close to the upstream toe of the dam as judgment allowed. Based in part on the results of the stability analyses, the wall location varies from the upstream toe of the dam to 25 feet upstream of the toe.

Stability analyses were performed on critical sections of the embankment (e.g., highest embankment section, thickest caliche and alluvial deposits, deepest excavation, high ground water, etc.), and the results were used to optimize the wall alignment. Stability was analyzed using UTEXAS3 by Edris and Wright (1992). This program computes the limit equilibrium factor of safety for an assumed shear surface employing a method of slices which, in this case, was Spencer's method of analysis. The trench stability was analyzed two-dimensionally (an infinite trench, not accounting for any potential increase in stability for arching effects of short trenches).

Since the design did not limit the contractor's panel size, the trench length could be determined by the contractor's operations and capabilities without concern for stability. Conservative slurry characteristics and strict QA/QC policies were required by the design and specifications. This is necessary because excavation by the slurry trench method relies on the density of the slurry to provide the necessary hydrostatic force and the formation of a filter cake to allow full mobilization of the hydrostatic forces on the sides of the trench. Analyses assumed that full mobilization of the slurry's hydrostatic forces occurred during excavation. Conservative analyses were required because of the close proximity of the embankment to the trench excavation.

Reservoir levels will be restricted during construction to facilitate construction and reduce cutoff wall construction costs. The Middle Concho pool will be restricted to EL 1920 during a period of construction to facilitate wall construction in the vicinity. The South Concho pool cannot be lowered below the invert elevation of the equalization channel, which is at approximate EL 1925. This allows more than half the cutoff wall to be constructed in the dry, while preserving project benefits for the water users. For the portions of the wall below the pool levels, cofferdams will be installed to allow construction of workpads against the upstream face of the dam. The cutoff wall will be constructed from the top of the workpads (figure 2). The workpads are sized to provide working room, and the top elevation of the workpads will be 5 feet higher than the reservoir elevation to ensure that the slurry level in the trench is always 3 to 5 feet above the reservoir level. The workpads will be part of the permanent construction and will be constructed of impervious material to become an integral part of the seepage cutoff.

To ensure complete cutoff of seepage, the wall will be keyed a minimum of 2.5 feet into low permeability bedrock formation. This depth will be determined during construction by core drilling on maximum 100-foot centers along the alignment to a minimum of 10 feet into bedrock and water testing of the bottom of each hole. Also, the northern and southern ends of the cutoff wall will terminate in the existing embankment cutoff trench beneath the dam, 100 feet upstream of the dam centerline. At the ends, the cutoff wall will angle from the upstream toe toward the downstream, continue through the upstream portion of the dam, and into the existing cutoff trench.

After construction of the cutoff wall, a 6-foot-high blanket of earthfill will be constructed over the top of the wall and tied into the upstream face of the dam to ensure complete seepage cutoff. Figure 2 shows a typical section of the workpad and upstream blanket. A geomembrane and geotextile barrier will be incorporated into the blanket to assure complete cutoff in the event that desiccation of the blanket material occurs.

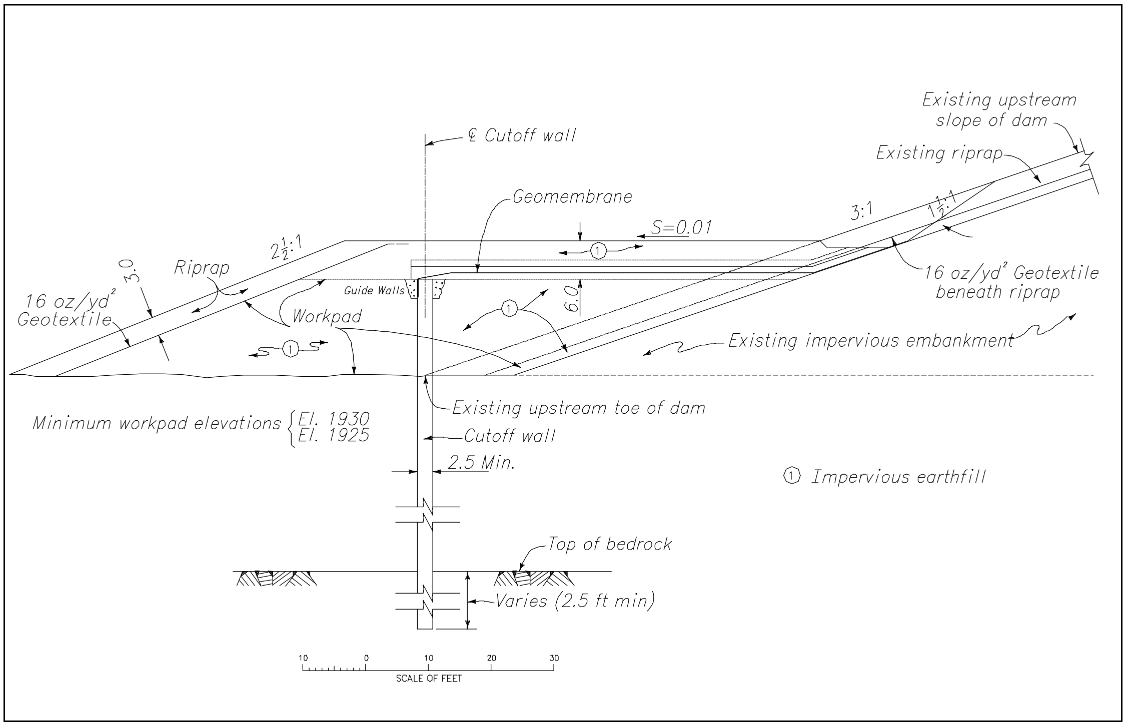

Figure 2.—Typical section of workpad and upstream blanket.

Construction Progress

The contract, for $38,352,544, was awarded on March 26, 1996, to Twin Buttes Constructors, which is a Granite-Bencor-Petrifond Joint Venture. The contract work is divided into two separate stages—Schedule 1, the test section, and Schedule 2, the remaining portion of the work.

Excavation of the cutoff wall began in July 1996 with the 1,200-foot test section. The contractor proposed constructing the cutoff wall in 50-foot-long primary panels and 8-foot-long secondary panels. Guide walls will be constructed along the entire length of the trench. Trench excavation methods included use of a hydraulic Kelly clamshell and cable-operated clamshells supplemented with chisels to breakup the alluvial material. In September, the contractor began using a Casagrande Hydromill for trench excavation. The S-C-B backfill is being prepared at an onsite batch plant. Backfill of the 50-foot primary panels is being accomplished by use of four transit mixers unloading simultaneously into four equally spaced tremie pipes.

Evaluation of backfill verification included excavation of two test pits which exposed a portion of the wall to allow visual confirmation of wall quality. Six verification holes were drilled at selected locations to obtain core of the S-C-B backfill, to perform permeability testing, and to perform geophysical investigations. Evaluation of all the data has not been completed at this time. Initial indications are that the S-C-B backfill meets the design intent.

The 1,200-foot test section was substantially completed in December 1996. Completion of the remainder of the cutoff wall and civil works required to integrate the cutoff wall into the existing dam are expected to be completed in early 1999.

Conclusions

While there is limited experience in the use of S-C-B backfill material, it was determined that S-C-B backfill, if construction techniques were carefully followed, could be utilized to provide a positive cutoff wall meeting the necessary strength and permeability requirements. The construction equipment and backfill placement procedures would need to be similar to plastic concrete procedures. Although the costs were significantly higher than S-B backfill, the S-C-B design provided flexibility to utilize local materials instead of concrete aggregates, and the lower strength required less cementitious materials.

View of Casagrande hydromill, Linkbelt LS218H 100-ton crane with 30" x 10' clamshell and Cat 773 end dump truck at Primary Panel No. 277.

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