NWRA Briefing

In the wake of the Teton Dam failure people all over the country are asking themselves and their friends and neighbors, "What do they need dams for, anyway?" Are they all unsafe?

Many of them are sending letters to their representatives in Congress and to the President asking that same question—not just about Reclamation dams, but about Corps of Engineers dams, State dams, district dams—all dams. Many of these letters suggest that all dam building be stopped. Immediately.

What do we need these dams for? You and the members of the NWRA know the answer to that as well as I do. We need them for water and power and food and recreation and jobs for people—for a lot of the same people who are asking the questions.

We're trying our best to answer these questions in Reclamation. But there are too many of them. And right now our credibility is suspect. In the eyes of many, we are a part of the "mess in Washington." We need your help.

Your members know what the dams and the powerplants, the canals and the pumping plants in their own areas have meant to them and to their States and the Nation.

I urge you to ask them to tell their friends and neighbors, the members of their social and civic clubs, their PTA's, their visitors from the East—tell them just how much those dams mean to the West, and to the Nation.
And when they are asked if the benefits are worth the risk, they can point out that Teton was the first of more than 300 Reclamation dams and dikes to fail in the Bureau's 74-year history; that more than 250 of those dams are earthfill; that, tragic as the Teton Dam flood was, Reclamation Dams have prevented more damages than were caused by that single failure—and saved more lives—than were lost there.

I have asked our Public Affairs Office to work with Carl Bronn to help develop some specific suggestions as to how your members can help combat what could become a serious threat to the construction of any dams anywhere in the United States. I understand Carl will be discussing this further with you later.
The shadow of doubt
Failure of a big dam is awesome because like an earthquake, it unleashes natural forces of heroic proportions to run loose with cosmic unconcern for people and their puny works. When the cause comes to light quickly, though, and it is one that could have been avoided, it is reassuring.

But what if the reason escapes discovery? What if the designer has experience and know-how hard to match anywhere and the contractor has been building dams for decades—and still the worst happens to their dam and they don’t know why?

That is the way it is with Teton Dam (see p. 9). The owner-designer and the contractor can put their knowledge, experience and reputations in dam-building up against anybody’s anywhere in the world and not risk being outclassed. They wrote the book.

Still, something vital and not yet understood went wrong and destroyed Teton Dam.

Shock waves from this collapse may take years to die away, especially if the cause of failure is not unequivocally identified. In sciences as empirical as soil mechanics, rock mechanics, foundations and hydraulics, success and failure are the ultimate, and sometimes the only, criteria in engineering decisions.

This was illustrated following the failure of a 218-ft-high thin arch dam (Malpasset) in the south of France in 1959. Reportedly a number of dam owners and designers with projects then in the planning or design stages switched from arches to other types even though engineers almost immediately identified the cause of failure as a clay seam under one abutment in what had been assumed to be solid rock. The designer was a recognized world authority on dams and had designed a number of remarkable and innovative arch dams. Other designers and owners may have reasoned, understandably, that if it could happen to his arch dam it could happen to anybody’s.

Earthfill dams have too long and well established a success record to be thrown into serious doubt by the failure of Teton Dam. Nevertheless, many designers of earthfill dams will be uneasily aware of an unanswered question until the investigators come up with a clear and convincing explanation of why the Teton fill behaved as it did.

Antitrust changes need more thought
Although the Senate last week diluted the more objectionable features of comprehensive antitrust legislation, the measure still spells trouble for the design professions, already under federal antitrust attack and the subject of random antitrust sniping from state officials, and the many small builders and suppliers that make up the bulk of the construction industry.

Well-intentioned, the legislation proposes to
strengthen antitrust law enforcement where deficiencies have permitted some businesses to exploit the absence of competition at the expense of citizens without the legal or financial clout to strike back. However, the measure holds a real risk of catching the innocent as well as guilty within its legal web, and ultimately raising the cost of goods and professional services.

Under the Senate bill's main provision, already passed by the House, state attorneys general would have the power to file class action suits for alleged antitrust violations on behalf of citizens and to collect triple damages for proven price-fixing and single damages for other antitrust violations. Both houses discarded the idea that private lawyers be given the power to pursue such cases for the state on a contingency fee basis for fear this would lead to a boondoggle for fee-hungry lawyers.

Yet there remains the threat that politically minded state attorneys general will initiate large suits as a way to get publicity that could advance their careers. As a result many small firms, innocent or not, could have their operations tied up and their access to financing threatened. Those who survive would have to pass on the huge costs of litigation and settlements to the public or consumer in the form of higher prices.

The construction industry, like many others, is already the target of much baseless litigation in which lawyers have huge political or financial stakes. Providing another legal heyday is not the solution for correcting inadequacies in class-action suits.

Take transit where it's wanted

Despite the high price the private automobile is exacting in air and noise pollution and congestion in urban areas, many urban dwellers are willing to pay it. Those in Los Angeles demonstrated it last week with a vote showing yet again that their love affair with the automobile is not over (see p. 11).

By the 60% to 40% defeat of a proposed rail transit network that would have served 44 of the county's 78 cities, Los Angeles County voters for the third time in eight years served notice to officials that not only do they intend to stick with their autos, but that they don't intend to finance a rail transit alternative.

The first time around in 1968, voters turned down a $2.5-million bond issue to be secured by property taxes. In 1974, they voted no to a $6.6-billion plan for an extensive fixed-guideway system and exclusive busways. This time around they turned down a $5.6-million plan. It should be plain that residents don't want any form of fixed-guideway transit.

There are plenty of other cities that are willing to put up local financing and are just waiting for the word from Washington. Let's move on.
1. Suggest to program chairman of their civic and social clubs and PTA's that a person knowledgeable of a local or regional water resource development project be invited to discuss the benefits of that project to the community.

2. Accept such speaking engagements themselves, or pass on the request to local offices of BuRec.

3. Instigate celebrations marking the 20th, 25th, 30th etc. anniversary of the start of construction, completion of construction, first delivery of water, first generation of power on local projects. Stress during those celebrations the benefits those projects have made possible.

4. In lieu of formal celebrations, write letters to the editor pointing out such anniversary dates and cite the benefits the local community has received from the project.

5. In lieu of celebrations, following a long dry spell this summer, write letters to the editor pointing out how areas which do not have irrigation--and dams--are suffering but the areas served by Reclamation are not.

6. At the height of the recreation season write letters to editors saying how much you and your family enjoyed a weekend at a Reclamation lake and point out that the community should be grateful to the people who built that dam and to those who are paying for it.

7. During the flood season write letters to the editor saying thank God for blank dam—if it weren't there we would have suffered hundreds of thousands of dollars in damages, untold misery and possible loss of life.

8. Encourage your friends who run newspapers to write editorials along the lines above.

9. Encourage your elected officials to speak out in favor of multipurpose dams.

10. If you live in a convention city encourage your official greeters to point out that your local garden spot owes much of its charm and prosperity to your local water project—and the dams that make it possible.

11. Encourage visitors—and local residents—to visit dams and water supply facilities.

12. Distribute literature to motels and hotels concerning the benefits of your project.

13. Enlist support of County Agents to spread the word of Reclamation benefits.

continued on page 2
What Reclamation will do to help NWRA

1. If you will sponsor a celebration, Reclamation will do as much—or as little—of the planning as you wish.

2. Reclamation will help you get elective and/or appointive officials to your celebration. This will be no major problem in this election year.

3. Reclamation will furnish facts and figures concerning the benefits which have been derived from separate projects, if asked. In many cases, the benefits already exceed the cost of older projects.

4. Reclamation will furnish speakers for local meetings or will provide briefings for NWRA members who will accept speaking assignments.

5. Reclamation will, on request, furnish facts and figures for use in letters to editors, etc.

6. Reclamation will provide pamphlets on individual projects and/or the Reclamation program.

7. Reclamation will provide films on request.

8. If you need anything else, just ask.
Sample Benefits Information

Reclamation and Colorado

The people of Colorado benefit directly and indirectly from Federal Reclamation projects but the value of the program is not limited to within the borders of the State.

The Colorado-Big Thompson Project has become a showpiece of interest to water resource developers throughout the world, with its pioneering Alva B. Adams diversion tunnel to carry water from west of the Continental Divide to the eastern slope to provide a dependable water supply for 720,000 acres and also water for municipal and industrial use.

This complex project north of Denver is the largest in the State and its value has been proven many times over during years of dryness or drought.

Denver is the location for the Bureau of Reclamation's world-renowned Engineering and Research Center, which draws hundreds of foreign nationals each year to observe and study Reclamation's activities.

The Reclamation projects in the State stabilize agricultural production, provide water for municipal and industrial use and for recreational activities of people as well as producing hydroelectric power, providing flood control and other water management functions.

Sample (2)

What does Reclamation mean in Arizona?

If Reclamation or some other entity had not provided water for the Phoenix area, Arizona as we know it today could not have come to be.

The Valley of the Sun admittedly owes its great progress to the pioneering and progressive activities of the Salt River Project, one of the earliest Federal Reclamation projects, in providing a dependable water supply, hydroelectric power, and flood control. Recreation is now a major item among other benefits.

There is no substitute for water in the life cycle and without the benefit of Reclamation or a similar program, the quality of life now enjoyed in the Phoenix, Sun City, Yuma and other areas would not be possible. And the agricultural production permits a better diet for people all over the United States as well as fiber for clothing and other uses. Hydropower makes possible the operation of industries which contribute goods and products of benefit to the people of the nation and which strengthen the economy.

continued on page 2
Sample (3)

Washington State, Dams and Water

Federal dams and dams of other entities on the Columbia River and its tributaries have made possible agricultural and industrial development in the Pacific Northwest which is unparalleled anywhere else in the Nation.

Grand Coulee Dam and powerplants, built and operated by the Bureau of Reclamation, made possible control of the Columbia River waters and provided hydroelectric power for industry as well as water for irrigation, municipal and industrial use.

The other dams in the area, including those of Reclamation, the Corps of Engineers and other entities also provide water to improve the quality of life for people and hydroelectric power to benefit them and supply industries.

Reclamation projects such as the Columbia Basin Project have resulted in establishment of new towns and cities as a dependable water supply made desert areas compatible with a good quality of life for people.
Sample welcoming statement

Welcome to the Valley of the Sun. Arizona is the fastest growing State in the Nation and Phoenix is leading the way.... Some of you may have expected to see nothing but sagebrush and cactus in Arizona. Well, we still have plenty of that, and other growth and wildlife in our great desert. But we also have lawns and trees and shrubs and modern cities and clean industries—all made possible by the miracle of water. In Phoenix that water comes primarily from the Salt River Project, one of the first of the great Bureau of Reclamation multipurpose projects in the West. Today, with the tremendous growth that Arizona has been experiencing, we need more water. That need is being met by the construction of the Central Arizona Project which will bring water from Hoover Dam into Phoenix and Tucson.
PRESSURE GROUTING FOUNDATION ON TETON DAM

by Peter P. Aberle*

ABSTRACT

The construction of a grout curtain on Teton Dam was made possible by extensive investigations and a pilot grouting program. The occurrence of four different rock types, steep canyon walls, large voids, and tight schedules made it pertinent that special equipment be constructed to perform the work. Drills which were self-contained and mobile for easy movement, especially on steep slopes, and a high capacity batching plant were responsible for low overhead costs and rapid progress. The addition of calcium-chloride to grout mixes to accelerate hydration intended to reduce grout travel within the curtain area. Closure systems and pumping criteria were devised, which assured placing the necessary amounts of grout to attain a tight curtain.

INTRODUCTION

The Teton Dam, located on the Teton River, six miles (9.65 kilometers) northeast of Newdale, Idaho, (Figure No. 1) is a multizoned earthen dam rising 390 feet (118.9 meters) high above the foundation and is 3,200 feet (975 meters) long cresting at elevation 5333 feet above sea level. The dam is 1,725 feet (526 meters) wide at river elevation, contains 10 million cubic yards (7.65 million cubic meters) of earth material, and has a reservoir capacity of 288,300 acre feet (356 million cubic meters). The Teton Dam and reservoir are the principal features of the Teton Project, a multipurpose project, constructed by the United States Bureau of Reclamation for flood control, power generation, recreation, and supplemental irrigation water supply for 110,000 acres of farm lands in the upper Snake River Valley.

The principal appurtenant features of the project consist of a power-pumping plant, two outlet tunnels, two gate shafts, a spillway, and a 72-inch diameter pipeline. Figure No. 2 shows, from the downstream side, the related structures still under construction.

The determination of the grouting procedures to be used to construct an impermeable curtain for the foundation of Teton Dam was made after extensive foundation investigations and a pilot grout program were performed. Knowledge gained from the pilot grouting program enabled the subcontractor to design and construct specialized equipment to

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perform the work in a time span so as not to interfere with other related operations during construction.

Foundation treatment entailed injecting 496,515 cubic feet (14,060 cubic meters) of cement (1 cubic foot equals 1 bag), 82,364 cubic feet (2,333 cubic meters) of sand, 132,000 pounds (59,874 kilograms) of bentonite, and 418,000 pounds (189,601 kilograms) of calcium chloride into 118,197 lineal feet (36,026 meters) of drilled hole. A curtain of 864,000 square feet (80,268 square meters) was constructed at a cost of 3.8 million dollars.

GEOLOGY

The dam and reservoir site is in a rather steep-walled, narrow canyon eroded 300 feet to 600 feet (91 meters to 182.8 meters) deep into a welded tuff (rhyolite) flow which lies unconformably on a highly uneven surface of lake and stream deposits.
Figure No. 2 - Teton Dam and Power-Pumping Plant

Teton dam site was first investigated by the U.S. Army Corp of Engineers in July 1957 and included the boring of two diamond drill holes. The Bureau of Reclamation subsequently further investigated the foundation with a drilling program in 1961 which continued at intervals until 1970.

At the dam site, the river valley was floored by approximately 100 feet (30.5 meters) of river deposits consisting of silt, sands, gravels, cobbles, and boulders. Beneath these deposited materials, there also occurred an intracanyon basalt flow present as an erosional remnant in the left canyon side. The basalt, 95 feet (28.9 meters) thick, was separated from the underlying welded tuff by 5 to 15 feet of tuff breccia and gravels. Figure No. 3 illustrates a profile of the foundation along the grout cap.

During investigations, water tests performed in core drill holes indicated that the abutment areas lying above the 5,100 foot elevation to be very pervious. Initial investigations showed that the weld tuff from the canyon floor to about 200 feet (61 meters) above the canyon floor was massive and formed large cliffs and ledges. The welded tuff in the upper 100 feet (30.5 meters) of the canyon walls was quite
PROFILE OF TETON DAM ALONG THE GROUT CAP

NOTE: 1 Foot = 0.305 Meters
inconspicuous and covered mostly by thin, slabby talus fragments and slope wash.

PILOT GROUTING PROGRAM

To further determine the feasibility of the damsite, the Bureau of Reclamation in 1968 performed a pilot grouting program on the left abutment and also a program was developed to determine the groutability of the alluvials located beneath the intracanyon basalt flow. This program, performed with conventional grouting equipment, showed that it would be impractical or extremely costly to construct a curtain in the upper 70 feet of the foundation above elevation 5100, and it was determined it would be more economical to remove this part of the abutment than to provide a grouting program that would adequately seal this area. Accordingly, a key trench was excavated in each abutment to remove the more jointed and fractured rock.

DRILLING AND GROUTING EQUIPMENT

DRILLING EQUIPMENT. To drill and grout the foundation, sophisticated equipment was constructed to perform the work. Two thousand feet (305.8 meters) of coggd track was fabricated to provide mobility for the drilling equipment. This track consisted of sections 3- to 12-feet long which were connected with roll-pins and anchored over and to the grout cap concrete. Figure No. 4 illustrates the track installed on the right abutment of the dam.
Two diamond drills manufactured by Machinery Services Inc., Grants, New Mexico, were modified and mounted on hydraulic-operated tilting platforms. These platforms enabled the drills to be adjusted between a vertical and 45-degree slope. A horizontal boom which could slide to either side of the drill, allowed the drill to be moved 11 feet (3.4 meters) in either direction of centerline to accommodate the drilling of the upstream and downstream curtains from the centerline position. The drills were powered by hydraulic motors, which in turn were powered by a hydraulic pump driven by a 43-horsepower, air-cooled diesel engine mounted on a pivot to facilitate operations on slopes.

The drill was controlled from a panel on the drill with fine and course feed controls and gauges showing oil pressures for vertical and rotary motions. Figure No. 5 illustrates the drill operating near station 22+00 on a centerline curtain hole with the control panel to the right of the drill.

Figure No. 5 - Diamond Drill Drilling Vertical Hole
The drill, engine, and a 3-ton capacity electric crane attached to one drill, were mounted on individual synchronized hydraulic motor-powered carts which could negotiate 1:1 slopes at a travel rate of 6-feet per minute. A hydraulic hoist on a cart was attached to the drill cart only as a safety measure while moving the drill on steep slopes. A separate control panel was located on the drill cart to move the horizontal boom from side to side, move the drill along the boom, and to operate the safety hoist and the carts.

The 3-ton electric crane was used to move grout pumps and other heavy equipment into desired positions along the grout area. Figure No. 7 shows one of the drills located in the vicinity of station 11+20 in the right abutment key trench on a 1:1 slope.

Diamond plug bits were used exclusively for drilling AX size (1 7/8-inch diameter) holes. AW size flush joint casing (2 1/4-inch O.D.) was used to over-drill lodged drill rods.

Figure No. 6 - Diamond Drill Located on Slope with Attached Equipment
AUTOMATED GROUT PLANT. To facilitate the use of bulk materials, a centrally located, winterized batch plant consisting of three mixing tanks, a silo for cement, and a hopper for sand was constructed 200 feet upstream of dam station 28+00 at the top of the left abutment. The cement and sand were delivered from a silo and hopper, respectively, into a 5,000 pound (2,268 kilograms) capacity scale hopper from which the ingredients were conveyed to the mixers. Calcium chloride and bentonite, when required, were measured in calibrated containers and added to the mixers manually. The plant was totally operated by compressed air.

This batch plant was capable of batching 250 cubic feet of cement or cement-sand per hour and deliver it to pumps located at the grout holes. The plant was used for approximately 1 year, and all pressure grouting between stations 16+80 and 34+00 was performed using this batch plant. Approximately 160,000 cubic feet of grouting materials were injected during this time.

To increase speed and accuracy of batching and to provide a visual and printed record of the grout mix ingredients, the plant was completely renovated and reconstructed on the right abutment 200 feet downstream of dam station 6+60. All grout mix ingredients were stored in silos and bins. The cement and sand silos were equipped with high and low content monitors which were tied into an electronic control system to prevent the operation of the plant at low content. The content indicators engaged a visual and aurial alarm when the silos were either full or nearly empty. Cement was stored in two 4,000 cubic feet capacity portable trailers, from which the silo could be filled pneumatically, and sand was stored in an auxiliary hopper from which it was conveyed over a vibratory screen to remove oversize, prior to storage in the silo. The sand was dried, to keep it from sticking and freezing during cold weather, by injecting heated compressed air through perforated pipe installed in the floor of the stockpile.

Each bin and silo had an associated feeder screw and vibrator. The ingredients were measured on a timed basis (pounds per second) and programmed on a timer control panel located in the plant. An almost infinite variety of formulas for a batch could be produced by setting the timers for each ingredient. After delivery of the ingredients to the mixing tub, the timers would automatically reset to their original setting. The delivery belts were also controlled by the timer panel and were wired to stop operations upon a failure and provide a variable runout time, or belt cleaning period, following a delivery of the ingredients constituting a batch to the mixing tubs.

All formulations were connected in series through the complete delivery chain so that only the selected formula would be batched. The final delivery belt was also connected so that it aligned with the proper mixing tub to activate the final delivery belt with the related designated formula. After the operator aligned the final delivery belt over the selected mix tub, he could run as many batches as required simply by pushing one start button. With three mixing tubs, three holes could be grouted simultaneously. Formulas to each tub or hole could be changed instantaneously by the operator resetting the timers.
at the inspector's request. It was possible to run a 10 cubic foot batch every 45 seconds.

Figure No. 7 shows the plant after the winterizing cover building was removed. At the far right is the vibratory sand screen from which the sand was conveyed into the 115 cubic foot silo. In the center are located the calcium chloride and bentonite bins and the 1,000 cubic foot capacity cement silo. The conveyor on the left is the final delivery belt to the mixers. The bentonite and calcium chloride bins were filled with an elevator which can be noted adjacent to the cement silo.

As the ingredients were being metered, digital totalizers counted each second of delivery of each product. Digital totalizers also counted the number of batches of each formula that was batched for each mixer. These totalizers were mounted in the timer panel and were for the operators' information. The same function of counting was also remotely available in an office where, in addition, totalizers recorded the total individual ingredients accumulated for an 8-hour shift operation.
The same count information was also fed to an electronic printer which recorded on a 6-inch wide continuous tape the time of day, the formula, the tub number used, and the number of seconds of each product used. Figure No. 8 is a schematic diagram of mixing plant with timer and recording panels.

Figure No. 8

DIAGRAM OF GROUT PLANT.
The mixing tanks were vertical cylindrical tanks with a capacity of 19 cubic feet. The grout was mixed by high-velocity, air motor-driven, centrifugal pumps; and by proper manipulation of a three-way (squeeze) valve, the grout could be continuously circulated in the mixing tub or transferred to the individual grout pumps located at the grout hole through 2-inch (5.08 centimeter) diameter quick coupled pipelines. Water for mixing grout was injected through a meter (for calibration) into a float controlled closet. By manipulation of an air control valve, the water was automatically pumped into the mixing tub and the closet refilled to the predetermined volume set on a float. Water added to the closet was always kept at 1 cubic foot less than the designed batch required. A 1 cubic foot water jacket was attached to the mixer; and after a batch had been delivered to the grout pump, the 1 cubic foot of water from the jacket was automatically injected into the grout line with a compressed air chase to wash and clear the 2-inch diameter grout supply line between the mixer and the grout pump located at the grout hole. The grout was transferred distances up to 1,800 feet without any serious plugging problems occurring.

Communications between the grout pumps at the grout hole and the mixing plant were achieved by the use of waterproof mine telephones. These telephones were also equipped with signal lights for ordering batches. Three separate light systems, one for each mixer, were incorporated to facilitate operations between a grout pump and its designated mixer at the plant. The telephone system was also equipped with a separate amplified paging system to call a desired person or persons to the telephone who may have been at some distance from the telephone. Telephones were located at the office, repair shop, mixing plant, and at each grout pump located at the grout hole. The main telephone line had numerous outlets and the telephones were equipped with extensions so they could be readily moved to where they were required.

Grout pumps used to inject grout into the holes consisted of air-operated, high pressure, duplex piston type pumps in conjunction with 25 cubic feet agitator tubs. The pumps were usually located in close proximity of the hole being grouted. The grout was pumped to the hole through circulating lines and a gauge equipped manifold. One and three-eighths inch I.D. flush coupled packer pipe utilizing leather cup packers were used to inject the grout into the hole. Packers and packer pipe were inserted into holes with an air-operated ram.

As revealed during the pilot grouting program, the insertion of leather cup packers was difficult because of sharp, broken rock fragments which protruded from the grout hole side walls and usually damaged the leather cups. A light gauge plastic canister was developed which could be slipped onto the packer and inserted to within a short distance of the bottom of the hole. Water under pressure was then applied and the canister was forced off the packer. In all cases, when the canister was forced from the packer, it could be easily detected by a slight drop in pressure as the canister was released. The packer could then be raised to the desire setting.

During grouting, packers sometimes became lodged in the hole by the grout bypassing the packer through fractures, joints in the rock, over-
size holes, and/or damaged leather on the packer. This made removal of the packer difficult if not impossible at times. Consequently, packers were constructed using an aluminum inner-body with reverse threads and plastic spacers between the leather cups. If the packer pipe could not be unscrewed from the packer, the packer pipe could be over-drilled using EX (1 5/8 inch I.D.) casing with a diamond casing bit. The plastic spacers and leathers could be easily ground up in the hole and the packer body and packer pipe removed from the hole. No hole was lost or required re-drilling during the grouting program due to unrecovered packers or packer pipe in a hole.

FOUNDATION KEY TRENCHES

During the excavation of the foundation key trenches on both the right and left abutment, several open fissures diagnosed as extinct fumaroles were uncovered. The fissures, which were related to the joint system, usually occurred in 3- to 6-inch widths and were partially to completely healed with calcium carbonate, or partially rubble filled. However, in the vicinity of station 4+40 in the right abutment key trench a fissure with an opening of 6-feet was encountered. This fissure was explored and mapped for about 75 feet on both the upstream and downstream side of the key trench. The fissure, shown in Figure No. 9 pinched down to 0 to 12 inches in both the horizontal and vertical direction to make it inaccessible for more extensive exploration. It was determined that it would be impractical to grout an opening of this magnitude without constructing a barrier to keep the grout from travelling excessively beyond the limits of the grout curtain.

Two 10-inch (25.4 centimeters) diameter holes were drilled and cased as close to the excavated key trench as possible without endangering workmen or equipment. For these reasons it was impossible to locate the holes near the high point of the fissure.

Through these holes a high slump concrete was dropped. Concrete was also placed into the exposed opening of the fissure during embankment operations to completely seal the opening that was in contact with the embankment. Figure No. 10 shows the fissure opening on the upstream side of the key trench.

DRILLING AND GROUTING PROCEDURES. From core drill holes, water tests and the pilot grouting program, it was determined that an impermeable barrier could be obtained by the construction of a grout curtain containing three rows of grout holes above elevation 5100 and in the basalt inflow, and a single grout curtain across the canyon floor.

In addition to the curtains, blanket holes, drilled at random depths and directions, were located to perform special treatment of open fissures, cracks, jointed areas, and other defects disclosed during excavation of the foundation. The curtains were located 10 feet apart with the centerline curtain located on the grout cap. The base 80-foot pattern in the centerline curtain consisted of holes 260-60-110-60-160-60-110-60- and 260-feet minimum depth spaced at 10-foot centers. The pattern holes were deepened to 310 feet in the spillway area due to
higher collar elevations. Holes in the downstream curtain were vertical while the upstream and centerline curtain holes angled 30 degrees from vertical toward the abutments, parallel to the grout cap. Closure holes between the 80-foot centers were deepened, depending on grout takes in the original pattern holes and subsequent closure holes. When grouting was initiated in an area, the blanket holes were completed first, followed progressively by the downstream curtain, the upstream curtain, and the centerline curtain. No grouting was initiated in the upstream and grout cap curtain until all holes within 80 feet had been completed in the proceeding curtain. No closure holes were drilled in the upstream curtain and downstream curtain to less than 20 foot spacing regardless of the grout take in the adjoining holes with exception of the downstream curtain in the basalt intraflow area. In the centerline curtain, closeout holes were drilled as required to attain final closure. In the basalt intraflow area the downstream curtain was primarily designed to grout the alluvial material below the basalt, and it was anticipated that some difficulties would be encountered in obtaining an impermeable curtain in this area. During the pilot grouting program it was ascertained that the basalt and the alluvial would be difficult to drill due to caving; and
although the alluvials accepted grout quite readily, only nine holes were drilled during the program. The downstream curtain was therefore designed to be drilled on 10-foot centers with vertical holes to help alleviate caving problems, with all holes penetrating the alluvials. Excellent closures were obtained with the downstream curtain; therefore, it was deemed unnecessary to drill an upstream curtain. Only negligible grout takes occurred in the alluvials while grouting the centerline curtain.

Grout holes were drilled to their full prescribed depth before any grouting was done, unless a drill water loss of 50 percent or more occurred. In this event, the area was grouted where the water loss occurred by setting a packer directly above the loss area and grouting the stage to refusal, after which drilling would be resumed. Upon completion of drilling a hole, the packer was inserted and the hole was water-tested in stages with each stage grouted if a water take was indicated. Stages were set at 30-foot increments below the 100-foot depth of the hole and 20-foot increments above the 100-foot depth.

Grouting of a stage was required if the water acceptance rate at the required pumping pressure for grouting was greater than 2 cubic feet in a 5-minute period. Initially, a criteria of 1 cubic foot in 5 minutes was used; but experience showed that grout would be refused in all instances, so the water acceptance rate was increased to the higher quantity.

Grouting was terminated when the grout take was less than 1 cubic foot of grout mixture in the time and pressures shown below:

- 10 minutes at 50 psi or less
- 7½ minutes between 50 psi and 100 psi
- 5 minutes at pressures greater than 100 psi

Grouting was also terminated if less than 2 cubic feet (1 cubic foot equals 1 bag weighing 94 pounds) of cement per hour were being injected.

Grout mixtures used varied from an 8:1 to 0.8:1 water-cement (w/c) ration by volume (a 8:1 grout mix indicates a ratio of 8 cubic feet of water to 1 cubic foot of cement). When sand was used, a 1:1:1.2 to 1:1:1.6 water-cement-sand ratio was used. Pressures of 10 psi at the hole collar and increased by 3/4 psi per foot of vertical depth to the packer setting were used for all holes.

For grouting of the downstream and upstream curtains and blanket holes, a maximum of 5:1 water-cement ratio was used. An 8:1 ratio was used on the centerline (final closure) curtain. All packer settings were water tested prior to grouting and the starting grout mix was determined by the amount of water accepted in the 5 minute water test period. On the Upstream and downstream curtain and blanket holes, the following criteria was used:
Water accepted in 5 minutes | Starting Grout Mixture
---|---
30 c.f. or more | 3:1 w/c ratio
20-30 c.f. | 4:1 w/c ratio
20 c.f. or less | 5:1 w/c ratio

For the centerline curtain, this criteria was modified to:

Water accepted in 5 minutes | Starting Grout Mixture
---|---
30 c.f. or more | 5:1 w/c ratio
20-30 c.f. | 6:1 w/c ratio
20 c.f. or less | 8:1 w/c ratio

Grout mixes were changed when it was felt that a thicker mix would readily be accepted by the hole. When to change mixes was a judgment factor made by the onsite inspector and was based on rate to take, drilling characteristics, pumping pressure, and intuition or so called "feel of the hole" by the inspector. Only basic criteria was specified as mix changes could only be based on hole behavior and this was quite variable even within different stages within the same hole.

When large grout takes were encountered in any portion of any hole at lower than normal pressures, the grout mix was progressively thickened. Sand or calcium chloride was used only after it was definitely determined that a hole would accept thick mixes. Once it was determined that a hole was wide-open, intermittent grouting was performed by injecting 500 cubic feet of cement or cement and sand and then washing the hole with just enough water to clear the hole. Grouting was resumed after a 4-hour interval. Two percent of bentonite by weight of the cement in a batch was added to all mixes containing sand to facilitate keeping the sand in suspension during pumping.

Calcium-chloride was added to accelerate hydration of the grout mix and control travel within the curtain area. Laboratory and field experiments were performed to determine the proper amount of calcium-chloride to be used to achieve setting after the grout reached the area to be grouted. It was found that numerous variables such as mix water temperature, sand temperature, cement temperature, air temperature, rate of take of the hole, and distance of hole from the mix plant affected the set-up time and the injection time. A hole that was wide-open would usually accept grout at the rate of 250 cubic feet of sand and cement or cement per hour. The lapsed time between mixing and injecting the grout at this rate varied between 6 and 8 minutes. An initial set-time of 12 to 16 minutes was therefore desirous, so that the grout could adequately reach its destination before prematurely setting.

Due to these temperature variances of the grout ingredients, it was impossible to develop a useable criteria to accurately predetermine the amount of calcium chloride required to attain the desired set time. A
more feasible set of criteria was used based on grout temperatures at
the grout pump. From 2 to 3 percent by weight of cement of calcium-
chloride was added when the mix water temperature ranged between 75
and 80 degrees F. and up to 6½ percent of calcium-chloride was
required when the mix water temperature was in the 35 to 40 degrees F.
range. Grout would reach the critical temperature at 90 degrees F.
when using the warmer mix water and near 70 degrees F. when using the
colder mix water. Grout temperatures were monitored constantly at the
pump by the pump operator and the inspector so that the proper amount
of calcium-chloride required could be constantly adjusted. Water was
added to the grout mix at the pump on rare occasions when the grout
began its initial set in the tub before it could be injected. It was
of utmost importance that, when calcium-chloride was being used in a
gROUT mix, the temperature of the grout mix be kept as high as possible
without prematurely setting in the tub before it could be injected.
Adding lesser amounts of calcium-chloride only prolonged the set-up
time and increased grout travel distances which was undesirable in
holes which were determined to be wide-open.

CONCLUSION

Figure No. 11 gives a summation of all the drilling and grouting
quantities for Teton Dam. Although the drilling and grouting of
tunnels and shafts is not discussed in this paper, the totals are
included to show the scope of the work. The times indicated are for
actual drilling and grouting only, and do not include time required
for moving and setting up equipment. The specialized drilling equip-
ment constructed by the contractor to perform the work was greatly
responsible for the high overall actual drilling rates achieved.
Moving and set-up times for drilling were also greatly reduced as the
drilling units were mobile and self-contained and required only one
man to operate.

Although the grouting rate is largely dependent on rock conditions,
modernized equipment for moving pumps, setting and retrieving packers,
and a strict maintenance schedule was greatly responsible for an
efficient operation. Grout pumps were located within close proximity
of the hole being grouted at all times so it was only rarely necessary
to employ a manifold tender.

The automatic operation of the grout plant required only one full-time
operator. An additional operator was required when sand was being
injected. Up to 4,000 cubic feet of grouting material could be
injected in a single shift when utilizing thick mixes; and 80,000 cubic
feet were injected during a single month. A maximum total of 25 work-
men were employed on a three-shift basis during full operation. The
work was performed during a 36 month period, working intermittently as
working areas became available for a total time of 25 months.

The use of calcium-chloride to facilitate rapid hydration of the grout
mixes enabled the grouting of the fissures in the key trenches possible.
Strict and constant monitoring of grout mixes containing calcium-
chloride prior to injection was an absolute necessity in order to
achieve maximum results.
<table>
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<tr>
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<tbody>
<tr>
<td><strong>Downstream Curtain</strong></td>
<td>30,537</td>
<td>1,420.64</td>
<td>21.50</td>
<td>214,660 cem. 35,756 sand</td>
<td>8.20</td>
<td>4,833.98</td>
<td>51.80</td>
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<td><strong>Upstream Curtain</strong></td>
<td>18,289</td>
<td>601.19</td>
<td>30.42</td>
<td>38,838 cem. 2,734 sand</td>
<td>2.22</td>
<td>1,471.62</td>
<td>27.57</td>
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<td><strong>Centerline Curtain</strong></td>
<td>46,434</td>
<td>1,993.87</td>
<td>23.29</td>
<td>51,862 cem. 1,091 sand</td>
<td>1.14</td>
<td>1,960.14</td>
<td>27.01</td>
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<tr>
<td><strong>Blanket Holes</strong></td>
<td>1,555</td>
<td>103.11</td>
<td>15.08</td>
<td>52,296 cem. 35,576 sand</td>
<td>56.51</td>
<td>811.28</td>
<td>108.31</td>
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<tr>
<td><strong>Spillway Blanket Holes</strong></td>
<td>3,987</td>
<td>202.17</td>
<td>19.72</td>
<td>99,136 cem. 8,207 sand</td>
<td>26.92</td>
<td>1,921.25</td>
<td>55.87</td>
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<tr>
<td><strong>Auxiliary Outlet Works Tunnel</strong></td>
<td>6,596</td>
<td>239.36</td>
<td>27.56</td>
<td>10,196 cem.</td>
<td>1.55</td>
<td>756.72</td>
<td>13.47</td>
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<td><strong>Auxiliary Outlet Works Access Shaft</strong></td>
<td>950</td>
<td>48.99</td>
<td>19.39</td>
<td>266 cem.</td>
<td>0.28</td>
<td>45.00</td>
<td>5.91</td>
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<td><strong>River Outlet Works Tunnel</strong></td>
<td>6,519</td>
<td>553.20</td>
<td>11.78</td>
<td>10,009 cem.</td>
<td>1.54</td>
<td>663.05</td>
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<td><strong>River Outlet Works Intake Shaft</strong></td>
<td>732</td>
<td>47.91</td>
<td>15.28</td>
<td>6,029 cem.</td>
<td>8.24</td>
<td>453.38</td>
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<td><strong>River Outlet Works Gate Chamber Shaft</strong></td>
<td>2,598</td>
<td>102.38</td>
<td>25.38</td>
<td>13,223 cem.</td>
<td>5.09</td>
<td>585.60</td>
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<td><strong>Total</strong></td>
<td>118,197</td>
<td>5,312.82</td>
<td>22.25</td>
<td>496,515 cem. 82,364 sand</td>
<td>4.90</td>
<td>13,502.02</td>
<td>42.87</td>
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</table>

Note: 1 cubic feet of cement = 1 bag = 94 pounds = 42.63 kilograms
1 lineal foot = 0.305 meter
1 cubic feet of sand = 80 pounds = 36.29 kilograms

Figure No. 11 - Summary of Drilling and Grouting of Teton Dam
The low rate of take per lineal foot of hole of the centerline curtain holes in relation to the blanket, downstream, and upstream curtain holes indicates strongly that successful closure was achieved and a tight curtain constructed.

ACKNOWLEDGEMENT

Special thanks are extended to fellow employees of the Teton Basin Project who helped in the preparation of this paper, Morrison-Knudsen and Kiewit (prime contractor), and McCabe Bros. Drilling Company Inc., (sub-contractor), who constructed the equipment and performed the work. Special thanks is also due Mr. Lloyd R. Gebhart, Liaison Engineer, Grouting, U.S. Bureau of Reclamation, Denver Federal Center, Denver, Colorado, for his sound advice during the progress of the work.