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FOUNDATION TREATMENT USING PNEUMATICALLY APPLIED CONCRETE

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16. ABSTRACT

Pneumatically applied concrete (shotcrete) was used to treat various types of foundation irregularities at Sugar Pine Dam. The intent was to ensure a good bond between the embankment and the foundation, to develop a uniform shape to the foundation, and to reduce seepage along and adjacent to the contact between the core and the foundations. A study was made of the foundation treatment operation and of the results of the concrete tests.

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INTRODUCTION

The use of dental concrete as a foundation treatment is not new. This report discusses the various ways it can be applied on the rock foundation of a dam embankment and describes the specific methods used by the Bureau of Reclamation on the rock foundation of Sugar Pine Dam.

Sugar Pine Dam, a part of the Auburn-Folsom Project, is located in Shirttail Canyon, 40 km (25 mi) northeast of Auburn, California. The dam is a central core rockfill embankment 56 m (184 ft) high with a crest length of 180 m (590 ft) at elevation 1112.5 m (3649 ft). An ogee section spillway located on the left abutment is designed for the future installation of a 7.94-m (26-ft) radial gate. No facilities for power generation were constructed.

Dental concrete is used to fill voids or to form a leveling course that provides a more uniform area for application of additional pneumatically applied concrete or earthfill.

Some 2126 m^3 (2781 yd^3) of dental concrete was placed in the foundation: 1520 m^3 (1988 yd^3) as pneumatically applied concrete, 435 m^3 (569 yd^3) by crane and bucket, and 171 m^3 (224 yd^3) behind forms. The engineer's estimate for the job was 2000 m^3 (2616 yd^3); the overrun was 6.3 percent. The total area on the foundation cutoff covered with dental concrete was 50 percent.

CONCLUSIONS

Dental concrete, applied pneumatically, is a fast and efficient way of treating geologic discontinuities and irregularities exposed in a foundation. In the four areas at Sugar Pine Dam where the dental concrete to rock contact surface was exposed for inspection, the bond was found to be excellent, even where the concrete was placed against decomposed to intensely weathered material in a shear zone.

The methods and procedures used are thought to be reasonable. Placing dental concrete pneumatically expedited all phases of the dam embankment construction. No delays resulted from waiting for major areas to be formed or for concrete to be placed. The quantity of the concrete placed would have been much higher if it had to be formed.

The use of a truck-mounted concrete pump with an articulated placing boom was the most efficient way of transporting concrete to any part of the dam foundation. This equipment had the flexibility to pump into formed areas or into unformed irregularities. It was also able to shoot concrete over or into thin or restricted areas where protection against weathering was required. Using the concrete boom truck is an economical way of placing dental concrete, whether it be pumped or pneumatically applied.

CONSTRUCTION CRITERIA FOR FOUNDATION AND ABUTMENT SURFACE TREATMENT

After completion of the dam foundation excavation, additional foundation treatment was required under the impervious core and filter zones. The major purposes of this additional treatment were:

1. To develop a uniform shape to the foundation that would reduce near verticals and overhangs to slopes no steeper than ½:1.

2. To prevent or reduce seepage along and adjacent to the contact between the core and the foundation.

3. To improve the bond between the embankment and the foundation by proper shaping.

Where rock is exposed to form the foundation in the abutments and valley bottom, substantial treatment is normally required. It is general practice to provide more treatment beneath the impervious core section than beneath the upstream and downstream shells. In addition, the foundation beneath the embankment filter zones frequently receives the same treatment as the area beneath the core. The amount of treatment required depends primarily on the condition of the exposed rock and on the number of defects at the surface.

At Sugar Pine Dam, dental concrete was applied to the foundation surface at the contact between zones 1A and 2 for foundation shaping and treating geologic discontinuities and irregularities (fig. 1). The general construction for the treatment of the foundation was performed to eliminate vertical faces more than 0.3 m (1 ft) high or steeper than a ½:1 slope so that there would be minimal differential settlement or tensile cracking of the embankment.

All cracks, joints, and shear zones were treated. Treatment consisted of cleaning each opening by air and/or water jet, air spading, and barring it to a depth three times its width and refilling with concrete. The shear zones were treated to eliminate the contact path of permeability between them and zone 1A and to protect against piping of embankment into the foundation or loss of fines from the foundation into the embankment filter zones. All features, even of the narrowest, that extend upstream to downstream across the cone and filter zone contact require special attention.

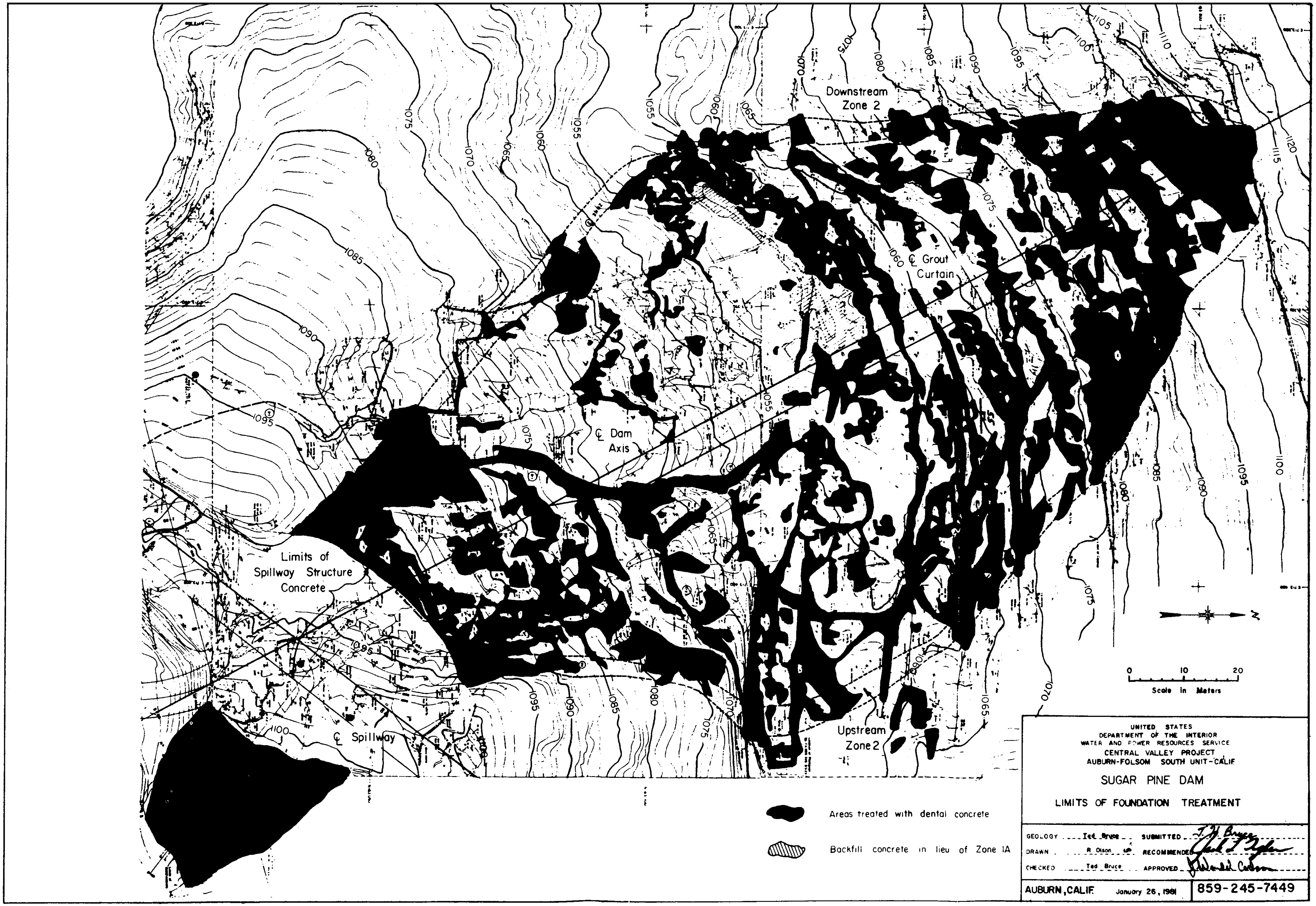

Figure 1. – Limits of foundation treatment at Sugar Pine Dam. Darkened areas were treated with dental concrete. 859-245-7449.

Foundation Preparation

The difference in the quality of acceptable foundation between the impervious zone and the remainder of the dam foundation is reflected in the cleanup required. Before embankment material is placed on any rock foundation within the impervious zone, the rock surface should be cleaned to remove loose and objectionable materials. In portions of the foundation outside the central contact area, cleanup by construction equipment usually achieved adequate results.

The cutoff trench was cleaned adequately with air and water as the original excavation progressed to allow geologic mapping (fig. 2). Before embankment placement, the foundation was marked for shaping and fault treatment. Only an adequate amount was marked to stay ahead of the contractor's operations.

General Geology at Sugar Pine Dam

The rock in the foundation is a fine-grained, dense amphibolite derived from low-grade metamorphism of volcanic flows and tuffs. The amphibolite rock is fractured with various types of geologic discontinuities, and two areas located in the upper left abutment contain intensely weathered and intensely fractured amphibolite. These two areas were treated with a thin 75-mm (3-in) blanket of pneumatically applied concrete. The most prominent geologic features in the foundation are the joints and the shear zones associated with joints. These joints were assigned letters during the preconstruction investigation. Listed below in order of importance with reference to pneumatically applied concrete are the joints with their attitudes.

Joints	*Range in strike*	*Range in dip*
A	N. 70° E. to E.-W.	45° to 65° N.W.
B	N. 70° W. to N. 87° W.	45° to 70° S.W.
F	N. 55° E. to N. 70° E.	35° to 42° S.E.
D	N. 15° E. to N. 45° E.	12° to 30° N.W.
C	N. 55° E. to N. 70° E.	16° to 30° S.W.
Foliation planes	N.-S. to N. 30° W.	65° to 85° N.E.

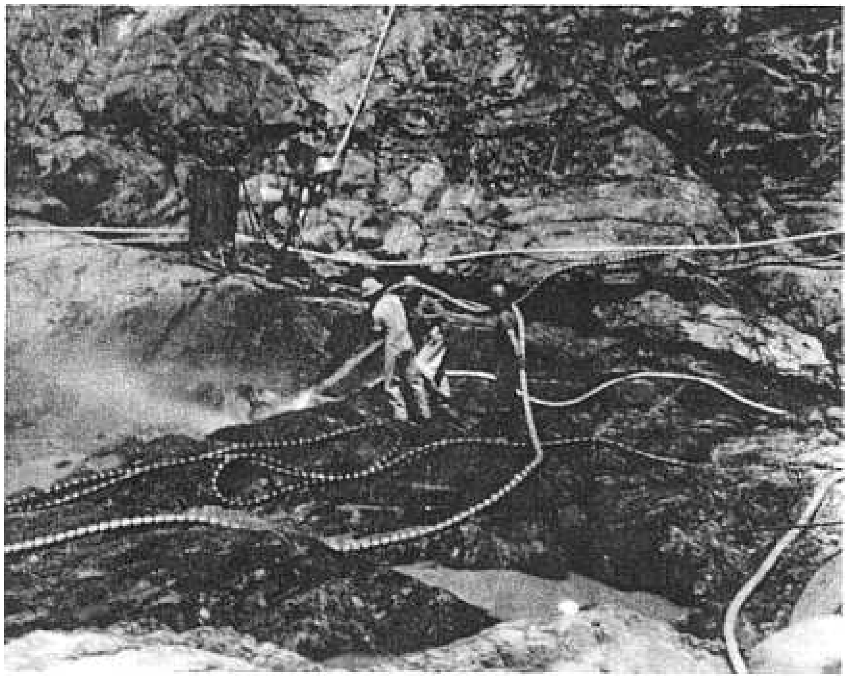

Figure 2. – Cleaning the cutoff trench foundation with air and water before geologic mapping. P801-D-81046.

Foundation Shaping Treatment

The A-joints strike nearly normal to the dam axis and dip steeply out of the left abutment into the right abutment. They predominate upstream of the dam axis in the lower left abutment and in the lower to mid-right abutment. The A-joints commonly created overhang irregularities ranging in height from 0.3 m to 1.5 m (1 to 5 ft). These overhangs were treated with pneumatically applied concrete for foundation shaping (fig. 3).

Occasional A-joint faces on the left abutment are steeper than ½:1 (63½°) (fig. 4). In such a situation, a bulkhead was constructed in an effort to hold the dental concrete. After dental concrete was applied to these faces, the slope was flatter than ½:1.

The B-joints dip steeply out of the right abutment into the left abutment. These joints are predominantly exposed on the right abutment downstream of the dam axis. As in the case of the A-joints, the B-joints create a similar problem with occasional faces steeper than ½:1. Consequently, these joint faces required a bulkhead and dental concrete flatter than ½:1. The B-joints created no problems on the left abutment.

The F-joints have similar attitudes to the B-joints but a flatter dip. These joints are generally exposed on the right abutment but do not pose any problems on the left abutment. The F-joints only

Figure 3. – Overhangs treated with pneumatically applied concrete for foundation shaping. P801-D-81047.

Figure 4. – A-joints on the left abutment that were nearly normal to the dam axis. P801-D-81048.

required dental concrete treatment when they were combined with foliation planes. On these few occasions a bulkhead was necessary to shape the slope.

Although D-joints were very prominent on the left abutment, they seldom required dental concrete treatment. These joints dipped out of the left abutment at a low angle and controlled most of the slope excavation. Only in combination with A-joints did any D-joints need treatment.

Foliation planes commonly created overhangs in the upstream 2:1 cut slope of the left abutment. In some cases, the overhangs exceeded 3 m (10 ft) vertically and required construction of a bulkhead (fig. 5). Occasionally, overhangs created by foliation planes were treated on the downstream portion of the right abutment.

Shear Zone Treatment

Most shear zones treated in the foundation cutoff area were sheared joints that had the same joint letter designation. Decomposed to intensely weathered material within the shear zones was removed to a depth of three times the thickness by air spading (fig. 6). After removal of the weathered material, dental concrete was applied as treatment.

A-joint shears are predominant in the lower left abutment and in the lower to mid-right abutment. Two predominant A-joint shears exposed in the right abutment were continuous from upstream to downstream (fig. 7).

A few D-joint and C-joint shear zones were treated on both the left and right abutment. One D-joint shear zone exposed in the lower right abutment is continuous from upstream to downstream.

One prominent shear zone, termed S-1, traverses diagonally from downstream to upstream in the left abutment. The strike of S-1 ranges from 30° N. to 50° W. and dips 25° to 35° N.E. or upstream and into the left abutment. Because of a special near vertical treatment excavation for S-1, bulkheads were required to hold the dental concrete.

Blanket Weathering Treatments

Two areas in the upper left abutment were treated with a thin, 75-mm (3-in) blanket of dental concrete. In both these areas the amphibolite was intensely weathered and intensely fractured. One area is located in the downstream portion of the left abutment below the spillway structure, and the other area is located left of the spillway.

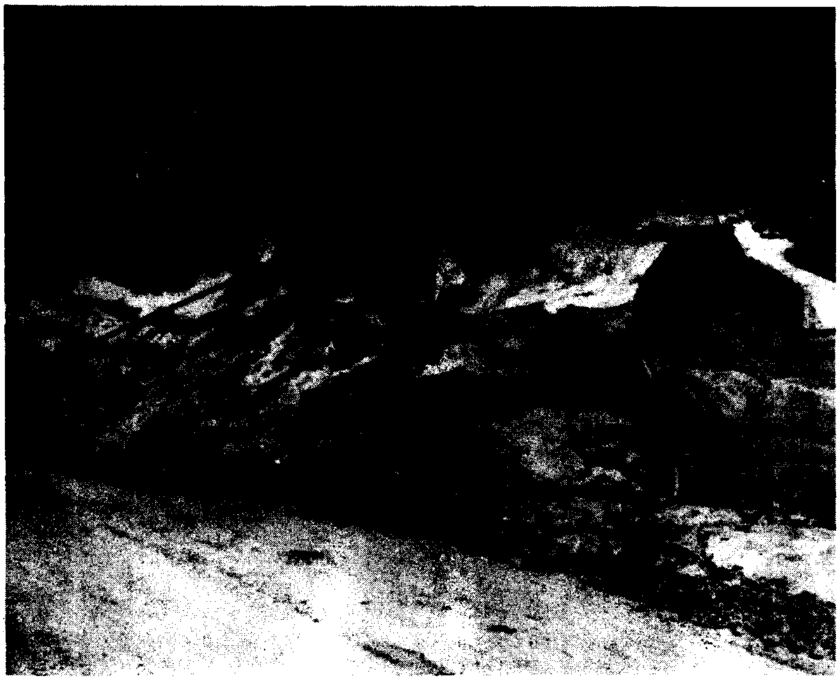

Figure 5. – Overhangs were backfilled by installing bulkheads and filling with conventional concrete. P801-D-81049.

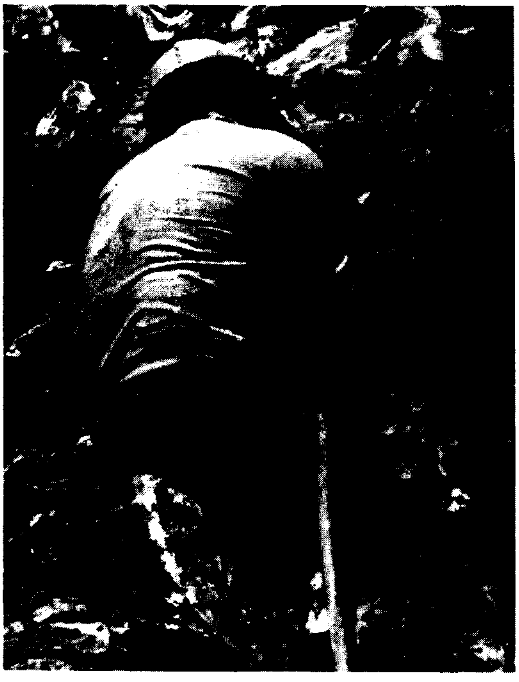

Figure 6. – Shear zones were removed with a hand-held air spade. P801-D-81050.

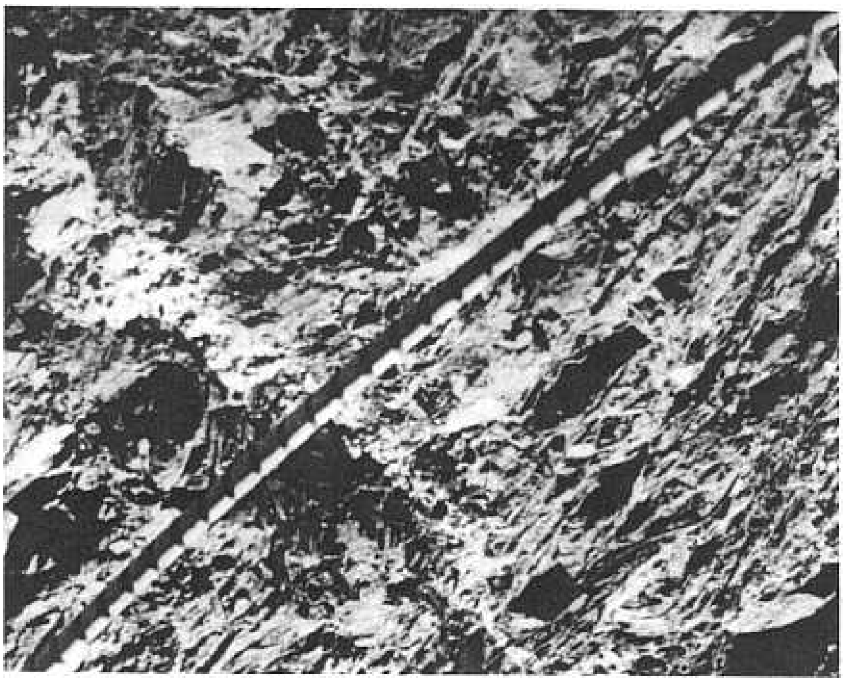

Figure 7. – A-joint shear. Across the upper right corner. P801-D-81051.

These blanket treatments were placed to protect the amphibolite from excessive moisture and freeze-thaw conditions. Exposure of the two areas to these weather conditions would cause further breakdown and excessive ravelling of the rock (fig. 8).

Where the catch point was nonexistent or limited, forming of concrete was required. Forms were placed on a ¾:1 to ½:1 slope with space between the rock to allow access behind the forms to consolidate the concrete with a vibrator. Concrete was then pumped behind the forms, using the pump without air pressure and nozzle.

Forming materials consisted of 4- by 6-inch (100- by 50-mm) whalers, 2- by 12-inch (50- by 300-mm) form material, she-bolts to hold whalers, and coil ties embedded in the rock.

One area in particular, on the right abutment, had a large bench that needed to be filled with concrete. A crane and bucket (fig. 9) was used to place a low slump, 19-mm (¾-in), concrete. The depth of the concrete ranged from 0.3 to 2.5 m (1 to 8 ft). In this instance it was more practical and economical to use the crane because the area was not formed, and the concrete was placed to a depth of 2.5 m (8 ft) (fig. 9).

Another method of placing dental concrete was by end dumping directly from the transit mixer into large holes in the river bottom where access was available. The concrete was then consolidated using a 75-mm (3-in) vibrator (fig. 10).

Figure 8. – Pneumatically applied concrete being placed on foundation material as protection against weathering. P801-D-81052.

Figure 9. – Placing low slump dental concrete on a large bench along the right abutment. A crane and bucket were used for transporting and placing the concrete. P801-D-81053.

Figure 10. – Large holes in the river bottom were filled with dental concrete. Concrete was dumped from transit mixers and consolidated with a 75-mm (3-in) vibrator. P801-D-81054.

PNEUMATICALLY APPLIED CONCRETE

A Thomsen 875 concrete pump was used to pneumatically place the 19-mm (¾-in) maximum size aggregate mix into the cracks and crevices (fig. 11) of all faults. A properly operating air compressor of ample capacity is essential to a satisfactory shotcrete operation. The compressor should maintain a supply of clean, dry air adequate for maintaining sufficient nozzle velocity for all parts of work while simultaneously operating a blow pipe for clearing away rebound. A 25-mm (1-in) air line was attached to the 89-mm (3½-in) nozzle, and a constant pressure of 700 kPa (100 lb/in^2) was used. This proved to be the most effective pressure for achieving a good bond with less than 3 percent rebound.

Rebound is aggregate and cement paste that ricochet off the surface during the application of shotcrete because of the collision with the hard surface or with the aggregate particles themselves. The amount of rebound varies with the position of the work, air pressure, cement content, water content, maximum size and grading of aggregate, and thickness of layer.

Initially, the percentage of rebound is large, but it comes less after a plastic cushion has been built up. Rebound is much leaner and coarser than the original mix. The cement content of the inplace

Figure 11. – Transit-mix truck delivering high slump concrete to the Thomsen 875 concrete pump. The truck boom and concrete delivery line are fully articulated and capable of rotating 360 degrees. P801-D-81055.

shotcrete is, therefore, higher because of rebound; this increases the strength, but also increases the tendency toward shrinkage cracking.

Rebound should not be worked back into the construction by the nozzleman nor salvaged and included in later batches because of the danger of contamination and of variability in the cement content, in the state of hydration, and in the grading of the aggregate.

The Thomsen 875 concrete pumper has a fully articulating boom capable of rotating 360 degrees. It is capable of pumping 96 m^3/h (125 yd^3/h); however, an average of only 18 m^3/h (23.5 yd^3/h) was attained because of difficult accessibility, the small size of the areas treated, and the fact that the truck had to move frequently because it could not reach beyond 24 m (80 ft).

The slump of the concrete was a maximum of 150 mm (6 in) at the pump. This was reduced to approximately 40 to 50 mm (1¾ to 2 in) by the loss of entrained air as a result of impact, the friction of the pumpline, and the blast of air at the nozzle. The resulting 50-mm (2-in) slump was found to be ideal for placing concrete on the rock foundation. Air temperature is a very important variable in determining the slump needed for the placement. When the wet shotcrete was placed, the air temperature was ±33 °C (±91 °F). As the air temperature during placing increased, an increase in slump was needed at the pump. Wet fogging of the surface rock is important before placing shotcrete, because it provides a better bond between rock and concrete.

One advantage of using the shotcrete method was that the full range of treatment required for filling cracks, openings, and excavated shears, and for shaping the foundation could be performed at this time. All sharp changes in the slope were reduced by placing the shotcrete as a filler.

The final rock surface should have smooth contours against which soil can be compacted by heavy equipment. In more extensive areas where there were large overhangs, multistage application was necessary to eliminate sagging of the shotcrete. This resulted in a void beneath the overhang. The ideal way of placing wet shotcrete beneath overhangs is to build it up in 150- to 200-mm (6- to 8-in) lifts, then to let it set or stiffen sufficiently before applying another lift. Satisfactory results were achieved with varying depths up to 1 m (3.28 ft) in thickness. There was excellent penetration into cracks and crevices and excellent bonding to the rock foundation. This was verified by an NX core sample taken on the left abutment beneath a large rock overhang (fig. 12).

After the wet shotcrete was placed, it was important to blow off with air or to sweep away with a stiff-bristled broom all rebound or loose material. This was done before applying curing compound to reduce the amount of compound required. This procedure provides a bonding surface free of unconsolidated concrete that, otherwise, could create percolation paths. It results in surfaces rough enough to provide adequate bonding of the earth materials.

Wet shotcrete was used for blanket treatment on highly weathered rock on the left abutment to prevent deterioration over prolonged exposure. This eliminated further weathering of the rock. A thickness of ±75 mm (2 to 3 in) was applied to this area with excellent results.

Concrete Control

The pneumatically applied concrete mix was tested both before pumping and after being discharged from the nozzle. Concrete cylinders [150 by 300 mm (6 by 12 in)] were cast from the batch before pumping for the purpose of testing compressive strength. At that time tests for slump, unit weight, and percent of entrained air were performed. One hundred millimeter (4-in) cubes were also made.

All the slump, unit weight, and percent entrained air tests were performed according to procedures in the *Concrete Manual* [1]*. The average results are shown in table 1.

100-mm (4-inch) Cubes. – The shotcrete cubes were made in plywood forms with a 100- by 100-mm (4- by 4-in) opening and a 100-mm (4-in) depth. One form was used for 16 cubes. The

* Numbers in brackets refer to entries in the bibliography.

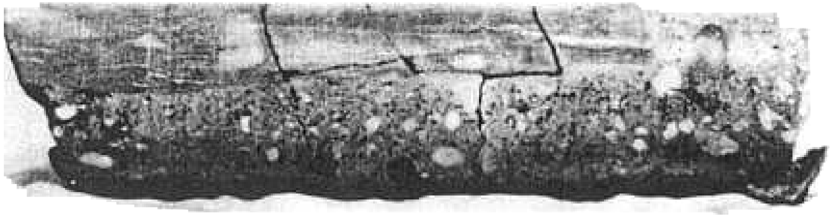

Figure 12. – NX core sample taken from the left abutment. P801-D-81056.

Table – Test results of pneumatically applied concrete[1]. Averages of 10 test batches.

	Before going into pump	Coming out of nozzle	Percent loss
Slump	121 mm (4¾ in)	37 mm (1½ in)	69.4
Percent air (gravimetric)	5.4	1.6	70.4
Percent air (air meter)	6.9	3.4	50.7
W/CP	0.71		
Unit Weight	2248.61 kg/m³ (3791.93 lb/yd³)	2342.90 kg/m³ (3950.93 lb/yd³)	

[1] Concrete mix consisted of 279 kg (615 lb) of cement, 65 percent sand, and 35 percent 19-mm maximum size aggregate per cubic meter.

shotcrete nozzle was held between 0.75 and 1.0 m (2.5 to 3 ft) away from and perpendicular to the box and moved back and forth across the box until all the cells were filled. The concrete was then struck off level with the box and allowed to set up for 24 hours. The cubes were then stripped from the box and stored according to designation 29 paragraph 4(b) of the *Concrete Manual.* These cubes were tested in compression at 2, 4, 7, and 28 days. The average strength of the 100-mm (4-in) cubes is plotted on figure 13. At 90 days (not plotted), the cubes had a strength of 27.7 MPa (4022 lb/in²).

6- by 12-inch Cylinders. – The cylinders were made according to designation 29 of the *Concrete Manual.* Average strengths are plotted on figure 13.

Observations

The size of the orifice on the discharge nozzle is very important. Experimentation was performed reducing the nozzle diameter (fig. 14) from 89 mm to 64 mm (3½ in to 2½ in). The same shotcrete

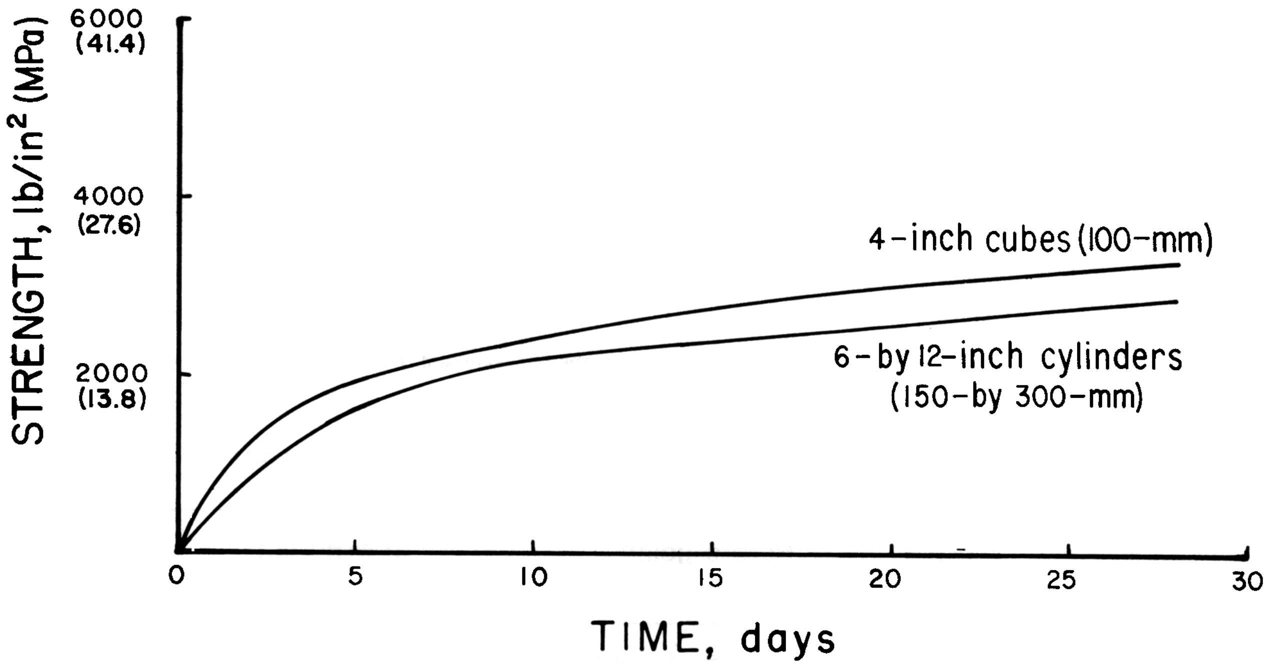

Figure 13. – Compressive strength of pneumatically applied concrete. A comparison of strength determined by testing 100-mm (4-in) cubes and 150- by 300-mm (6- by 12-in) cylinders.

Figure 14. – Shotcrete nozzle attached to delivery line. Note the air valve on the left. Compressed air is used to accelerate the velocity of the concrete as it leaves the nozzle. P801-D-81057.

mix and slump were used, but the shotcrete was wetter when discharged through the smaller opening because of the greater pressure. The nozzle diameter was changed back to 89 mm (3½ in). Through more experimentation, it was observed that the drier the concrete at discharge, the better bond to the rock surface. Furthermore, the shotcrete mix must have a higher slump at the pump hopper than at the nozzle. This higher consistency allows a more uniform flow from the pump through the hose and nozzle. Because of the lack of control of the flow at the nozzle, the pump operator regulates the flow. The person applying the shotcrete must maintain visual contact with the pump operator to instruct him when to start and stop the flow.

The pumpline became easily blocked with oversized aggregate, causing downtime of up to 1 hour to clear the line. Material used for shotcrete mix must be properly graded to alleviate this problem.

Suggestions For Applying Wet Shotcrete

1. Apply normal to the surface, less rebound will occur.

2. A good distance from the nozzle to the rock surface is 0.3 to 1 m (1 to 3 ft).

3. Apply beneath overhangs slowly enough to reduce or eliminate sagging.

4. Apply curing compound as soon as possible after placement. This will help reduce shrinkage cracks.

5. Before placing the embankment, slush grout shrinkage cracks in the same manner that other cracks are treated.

6. Keep lifelines ahead of placing to ensure some continuity on steep slopes. Lifelines are necessary on steep slopes for the laborer to be able to handle the nozzle.

7. Provide sufficient air pressure at the nozzle. This is important because proper air pressure reduces slump and sag in the concrete.

8. In open cracks, put the nozzle in the hole to ensure filling without voids.

9. Start at the bottom of the area to be treated with shotcrete and work up. This will eliminate the collection of rebound in depressions and cracks below the placement.

Inspection

The pneumatically applied concrete operation should be continuously inspected by a qualified inspector who should check materials, forms, reinforcing, ground wires, application equipment, application of material, curing, and protection against freezing. Each layer of shotcrete placed should be systematically sounded with a hammer to check for drummy areas. Cores should be taken from the structure as required to verify the quality of material in place, especially for structural shotcrete; such cores should be taken as early in the job as practicable so that the data obtained can be used to improve the later work.

BIBLIOGRAPHY

[1] *Concrete Manual,* 8th ed. rev., Bureau of Reclamation, Denver, CO, 1981.

"Recommended Practice for Shotcrete," ACI Committee 506 (ACI 506-66).

"Foundation and Abutment Treatment for High Embankment Dams on Rock," *Journal of the Soil Mechanics and Foundation Division,*" Proceedings, ASCE Vol. 98, No. SM10, October 1972.

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