Innovative Use of Bio-Polymers to Construct a Toe Drain at Piute Dam

The presence of an original unfiltered drain and liquefiable embankment and alluvial soils near the toe of 100-year-old Piute Dam in Utah led project owner Piute Reservoir and Irrigation Co. to construct a new deep drain beneath the downstream portion of the dam. The company chose a bio-polymer trench method, which would allow placement of filter/drain materials and drain pipes without incurring the cost of a dewatering program and deep, open excavation.

By Phil C. Gerhart, Steven R. Day, and Kurt Sorenson

In 2001, a team conducting geotechnical studies upstream and downstream from the crest of 90-foot-high Piute Dam in Utah confirmed the presence of an original unfiltered drain and liquefiable embankment and alluvial soils beneath the downstream portion of the dam. Because of this finding, project engineers and state dam safety regulators became concerned about the risks associated with a piping failure in the event of an earthquake. To reduce this potential risk of dam failure, project engineers and regulators decided to install a new deep downstream drain.

To construct the drain, dam owner Piute Reservoir and Irrigation Co. chose an innovative bio-polymer trench method, which is a modification of the conventional slurry trench. Several of the insights gained from this job could be useful to other engineers contemplating use of the bio-polymer trench solution.

Phil Gerhart, P.E., is president of Gerhart Consultants Inc. and was the design engineer for the work performed on Piute Dam. Steve Day is vice president of Geo-Solutions Inc., the subcontractor hired to build the bio-polymer trench. Kurt Sorenson is president of dam owner Piute Reservoir and Irrigation Co.

Original construction of Piute Dam

Piute Dam was built during the early 1900s by farmers and ranchers to provide a more stable irrigation water supply for their agri-businesses. Horse-drawn fresnos and wagons and a steam-driven pump were used to construct the dam, which features a 1,400-foot-long crest and impounds 72,000 acre-feet of water. The original builders sluiced soils from nearby borrow areas into central portions of the dam to provide an "impervious" core, which was tied into meta-conglomerate rock abutments. Downstream toe drains for Piute Dam consisted of coarse rock drains and wood stave pipes. The dam is still used today for irrigation.

Discovering an active fault

In 2001, the project team — consisting of representatives of the dam owner and the design engineer — conducted geotechnical studies upstream and downstream of the dam crest, in accordance with requirements of the state of Utah's Dam Safety Office. These studies revealed an active fault just downstream from the dam toe. Based on seismicity studies, geologists concluded that the Maximum Credible Earthquake event would be of moment magnitude 7.0 with peak ground accelerations of 0.45 g. Such an event would activate this fault.

More important than the proximity of the active fault were several existing conditions at the dam that made the structure's stability vulnerable in the event of an earthquake. These included:

— An unfiltered toe drain system;

— Potentially liquefiable pockets in the lower embankment and underlying alluvial materials;

— Potential for settlement of the alluvial material in the event of an earthquake; and

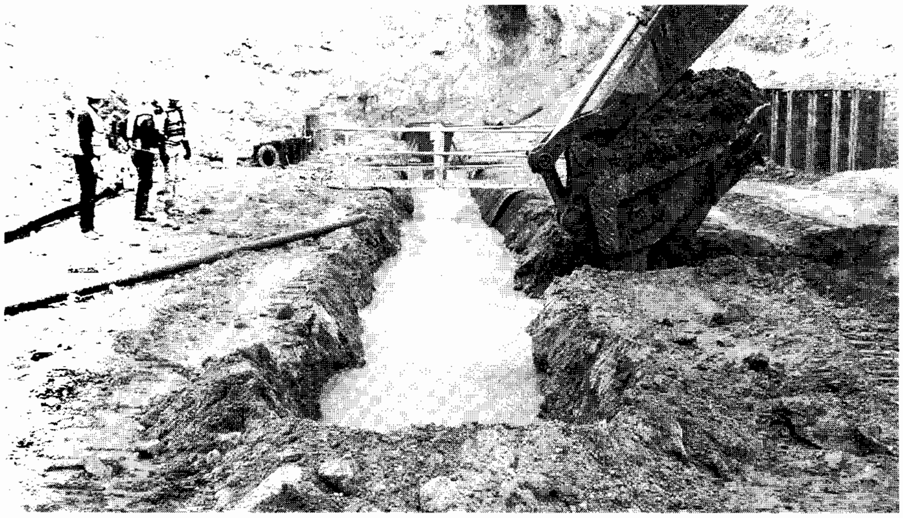
— Difficulty with monitoring flow from the existing toe drain.

Unfiltered existing toe drain

Project plans, specifications, and construction correspondence from the early 1900s — sometimes sketchy and occasionally contradictory — never mentioned use of any graded sand and gravel materials to envelope the specified "coarse rock" drain. In addition, although generally well preserved, sections of wood stave pipe do deteriorate underground. Therefore, there likely was little resistance to fine-grained material piping at the external boundaries of the existing toe drain system.

Potentially liquefiable pockets

Field studies performed by the project team in 2000 and 2001 documented the presence of liquefiable pockets in lower embankment zones and underlying alluvial materials. However, nothing suggested that these isolated areas were linked together in a layer continuous enough to constitute a potential failure plane. Primary concerns centered on the development of excess pore pressures during a seismic event. In addition, the design engineer was concerned about the possible transportation of fine sands and silts through and into porous rock zones, and particularly the existing toe drain system, as these excess pore pressures sought dissipation routes. In the engineer's opinion, connections between



During excavation of the construction trench at Piute Dam in Utah, the bio-polymer slurry (shown in the trench) was used to stabilize the trench walls and prevent groundwater from entering the trench. The trench remained full while the excavator dug under and through the slurry.

such potentially liquefiable pockets occuring in this manner — resulting in a relatively large-scale movement of materials — was a significantly more likely event than development of a failure plane.

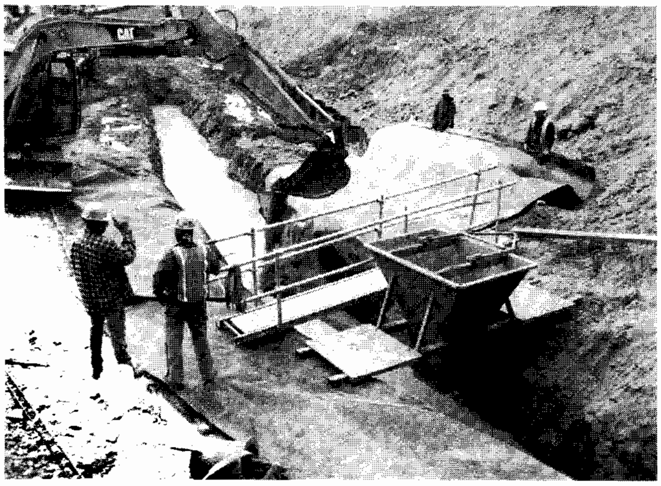
Earthquake-induced settlement

Documenting materials for dams constructed in Utah ten to 20 years after Piute Dam was built describe and show pictures of horse-drawn static compactors (generally concrete cylinders). However, there were no indications of this equipment being used during construction of Piute Dam. In fact, most interior materials were sluiced into position using a high-pressure water stream from a steam-driven pump.

In addition, results of standard penetration tests performed by the project team during field studies confirmed that soil densities, both in the embankment and underlying alluvium, were largely loose to medium-dense materials. It appears densification in the outer dam shells largely was confined to what could be achieved using wagon wheels and horses. Both embankment and alluvial materials contained gravels, making volumetric strain calculations difficult. However, the design engineer concluded that lower embankment and foundation material settlement would be sufficient enough during a major earthquake event that bridging, transverse cracking, and void development near the steep rock abutments were likely.

Toe drain flow monitoring

A further problem with the existing toe drain system was the difficulty associated with monitoring flows. Outlet pipe inverts (the low point of the inside diameter) were sufficiently depressed in elevation that flows could not be monitored during reservoir releases because the inverts were submerged by the downstream pool that developed. Thus, in the event of an earthquake and a need to release reservoir water, changing flow conditions in the downstream toe drain system could not be monitored.



Once the trench was completed, the contractor lined the downstream face with overlapping non-woven geotextile panels, followed by 60-mil sheets of high-density polyethylene (HDPE) geomembrane.

Deciding to replace the toe drain

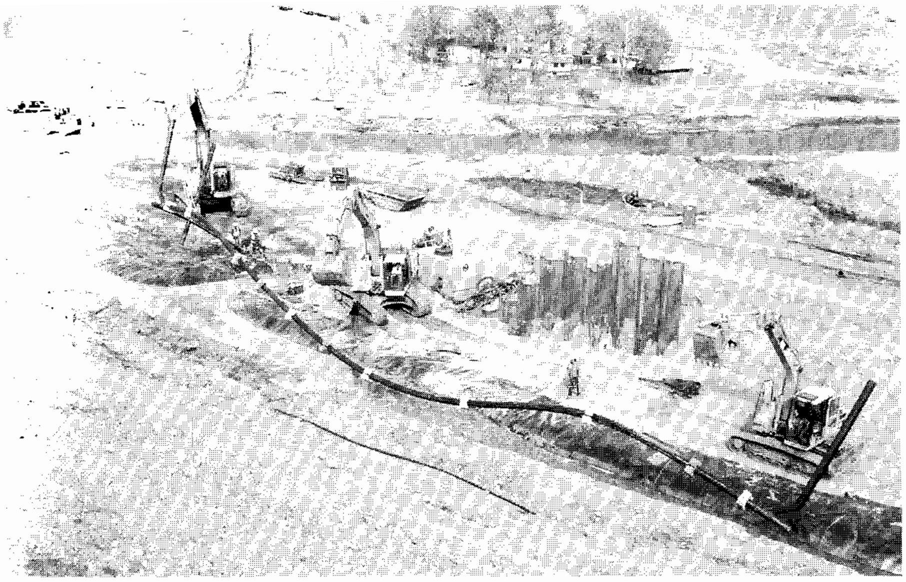
The design engineer and state regulators determined that the best approach to correct the problem would be to install a deep drain and remove or isolate the existing toe drain. Completion of this work would involve temporarily increasing the downstream embankment slope, requiring excavation and replacement of existing dam materials.

The design engineer considered two different excavation methods. One method was conventional open trench excavation. The other featured the use of bio-polymer trench techniques. Cost estimates made to compare the two methods showed that use of the bio-polymer trench technique would save about $2 million in construction costs. The dam owner chose this approach and contracted with general contractor ASI RCC in Buena Vista, Colo., and subcontractor Geo-Solutions Inc. in Littleton, Colo., to construct the drain using primarily bio-polymer trench techniques. Total value of the contract was $950,000.

Understanding the bio-polymer method

The bio-polymer method for constructing filters or drains is a relatively new modification of the conventional slurry trench. The conventional method uses bentonite slurry to stabilize the walls of the trench, but the bio-polymer method uses a bio-degradable slurry. Unlike bentonite, this bio-polymer will not permanently plug the trench walls. This allows drainage through the trench walls.

Although synthetic polymers are used in some applications, the most common polymer used is a carbohydrate polymer derived from the bean of the guar bush. This polymer is relatively low in cost and can be maintained with additives. In addition, guar gum slurry is easy to break down because it is in a constant state of degradation. Guar gum slurry serves as a preferred food source for natural soil microorganisms, so additives are used to slow biological activity and maintain the slurry's useful properties. The guar gum slurry also can be broken down by introducing chemicals or enzymes. When properly made and maintained, bio-polymer slurry retains a high viscosity and remains effective for about two weeks. Residual by-products (before consumption by soil micro-organisms) are simple sugars



After the geomembrane was placed to line the trench, the contractor installed a 10-inch-diameter perforated high-density polyethylene (HDPE) drain pipe at mid-level in the drain.

(mannose and galactose) and water.

The basics of building a bio-polymer trench are similar to those for conventional slurry trench construction. A hydraulic excavator is used to dig a narrow trench to typical depths of 15 to 80 feet. As the trench is excavated, bio-polymer slurry is pumped in so that the trench remains full at all times while the excavator digs under and through the slurry. The slurry stabilizes the trench walls, maintaining it at essentially the same width as the excavator bucket, and prevents groundwater from entering the trench.

What is unique about the bio-polymer method is that it allows placement of perforated pipe systems, geomembranes, and other elements without drawing down the reservoir or dewatering the excavation. When placed using the bio-polymer method, the drain elements simply displace the bio-polymer slurry, which then can be deactivated to decompose rapidly.

One drawback to the bio-polymer method is that, unlike conventional open trench excavation, the work cannot be visually inspected while it is being performed. However, other methods can be used to check the functionality of the system, including piezometers, pumping tests, and in-place permeability tests.

Installing the new toe drain

The work to install the new downstream drain at Piute Dam was completed in seven steps in the fall of 2005:

1) Temporarily excavate the downstream slope of the dam to an angle of 1.8:1 to create a 40-foot-wide work platform 80 feet below the dam crest.

2) Drive temporary sheet piling to keep bio-polymer slurry from entering the old drain system during construction.

3) Use a 3-foot-wide bucket attached to the boom of a hydraulic excavator to construct a 30-foot-deep trench 455 feet in length, then immediately fill the trench with bio-polymer to maintain the structural integrity of the walls. The [illegible] polymer used at Piute Dam was [illegible] 50 percent powdered guar bean [illegible] percent synthetic polyacrylam[illegible] tion mixed with water. Slurry [illegible] were maintained about 3 feet [illegible] top of the trench during exca[illegible]

4) Line the downstream [illegible] trench with overlapping [illegible] textile panels, followed by [illegible] of high-density polyethylene [illegible] geomembrane.

5) Place a 10-inch-diam[illegible] rated HDPE drain pipe [illegible] the bio-polymer-constructed [illegible]

6) Backfill the trench [illegible] filter/drain material and [illegible] vibrator to achieve spec[illegible]

7) Introduce chemicals [illegible] slurry from the bottom [illegible] assist degradation of the slurry.

Finally, ASI RCC rep[illegible] pacted the dam materials [illegible] create the work platform.

Lessons learned

During design and constr[illegible] new toe drain, several points [illegible] that could be of interest to [illegible] neers contemplating a [illegible] trench solution. A number [illegible] procedures, not performed [illegible] tional projects, were attem[illegible] completed for the Piute Dam [illegible] The authors hope the following [illegible] will aid further development [illegible] of this geotechnical tool.

— Initial bench scale [illegible] studies conducted at Brigham [illegible] University convinced designers [illegible] lators that pluviating (dumping [illegible] rials directly into the slurry with[illegible] a tremie) the graded filter/drain [illegible] would not result in material segregat[illegible] In addition, we could densify the filter [illegible] drain materials with a concrete vibrat[illegible] while the slurry was still active.

— Constructing a test trench at the dam site before starting drain construction was a useful exercise that enabled us to check contractor installation procedures, verify the attainment of design criterion, and establish final construction procedures.

— Relatively deep trench and steep slope combinations (a 32-foot-deep trench at the base of a 1.8:1 slope) with limit equilibrium method static factors of safety of 1.25 showed no movement (monitored by inclinometers), indicating that they are stable. ■

[illegible] Gerhart may be reached at Gerhart [illegible] Inc., 1890 East 850 South, [illegible], UT 84663; (1) 801-853-[illegible] E-mail: pgerhart8@msn.com. Mr. Day may be reached at Geo-Solutions, 26 West Dry Creek Circle, Suite 600, Littleton, CO 80120; (1) 720-283-0505; E-mail: sday@geo-solutions.com.

Reference

Gerhart, Phil C., Steven R. Day, and Eric R. Dixon, "A Bio-Polymer Drain Solution for Piute Dam," *Dam Safety 2005 Proceedings*, Association of State Dam Safety Officials, Lexington, Ky., 2005.