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 filterdrain materials and drain pipes without incurring the cost of a dewatering program and deep, open excavation.

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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.

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 fres- tos 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 mega-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 Creditable 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
- Difficulty with monitoring flow from the existing toe drain

Unfiltered existing toe drain

Project plans, specifications, and construction correspondence from the early 1900s—even sketches 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
such potentially liquefiable pockets occurring 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 Plate 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 Plate 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 severely depressed in elevation that flows could not be monitored during reservoir releases because so invert submerged by the downstream pool that developed. Thus, in the event of an earthquake and need to release reservoir water, changing flow conditions in the downstream toe drain system could not be monitored.

Deciding to replace the toe drain

The design engineer and state regulators determined that the best approach to correct the problems would be to install a deep drain and then either isolate the existing toe drain. Construction 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 ASH RCC in Basing, Colorado, and subcontractor Geo-Solutions Inc. to construct the drain using primarily bio-polymer trench techniques. Total value of the contract was $4.5 million.

Understanding the bio-polymer method

The bio-polymer used 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 bio-degradable slurry. Unlike bentonite, this bio-polymer slurry will permanently plug the trench walls. This allows drainage through the drain wall.

Although slurry polymers are used in some applications, the most common polymer used in some polymer derived from the bark of the guay tank. This polymer is relatively low in cost and can be modified with additives. In addition, guay tank slurry is easy to break down because it is a constant state of decomposition. Guay tank slurry serves as a pretreated food source for natural soil microorganisms, so additions are used to add biological activity and maintain the slurry's useful properties. The guay tank slurry also car can be broken down by introducing chemicals on 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 trench.

As the trench is excavated, the bio-polymer slurry is pumped in so that the trench remains full at all times while the excavator dives 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 HDPE systems, geomembranes, and other elements without drawing down the receiver or dewatering the excavated area. When placed using the bio-polymer method, the drain elements simply float on the bio-polymer slurry, which then gets deactivated and decomposes rapidly.

One drawback of the bio-polymer method is that it involves conventional open trench excavation, a work task that can be visually respected as it is being performed. However, these methods can be used to shield the biocompatibility of the system, including pumps, filters, pumping tests, and in-place performance tests.

Installing the new toe drain

The work to install the new toe drain at Point Dume was performed in seven steps. The following:

1) Temporarily constructed the downstream slope of the toe. The angle of the toe was set at 1:8:1 to create an ideal work platform 80 feet below the toe crest.

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

Use a 3-foot-wide bucket attached to the boom of a hydraulic excavator to contract a 32-foot-deep trench in length, then immediately fill the trench with bio-polymers to maintain the structural integrity of the walls. Trenches were maintained about 3 to 5 feet apart for stability.

Line the bottom of the trench with overlapping geotextile panels, followed by or high-density polyethylene geomembrane.

Place a 10-inch-rated HDPF drain pipe in the biopolymer-concrete.

Backfill the trench with filter/aggregate and a motorized vibrators to achieve compaction.

Introduce crushed slurry from the bottom to assist degradation of the problematic.

Finally, as ISF RCC repaced the dam material to create the platform.

Lessons learned:

During design and construction, the drain, several potential problems could have been identified by technical experts attending a trench solution. A number of problematic situations, not considered to be functional, were analyzed and completed for the Phase II.

The authors hope the lessons learned will aid future development of this geotechnical tool.

- Initial bench scale studies conducted at Brigham Young University convinced design engineers that placing dump materials directly into the slurry would result in a trench of the graded filter/drain material; tests indicated that the trench failed in material resistance.

In addition, they found that the drain fabrics, with a concrete cover, led to the failure, while the slurry was still active.

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

Reference: