A BIO-POLYMER DRAIN SOLUTION FOR PIUTE DAM

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Background

Piute Dam, located approximately 10 miles north of Junction, Utah was constructed during the early 1900’s by pioneer farmers and ranchers to provide a more stable irrigation water supply for their agri-businesses. Construction of the 90 foot high dam with a 1400 foot long crest, impounding 72,000 acre-feet of water, was completed using horse-drawn fresno’s and wagons and a steam-driven pump. Soils from nearby borrow areas were sluiced into central portions of the dam to provide an “impervious” core and tied into meta-conglomerate rock abutments. Downstream toe drains consisted of coarse rock drains and wood stave pipes.

Geotechnical studies conducted upstream and downstream of the dam crest, in accordance with State of Utah Dam Safety requirements, discovered the existence of an active fault just downstream of the dam toe. Seismicity studies concluded that the Maximum Credible Earthquake event would be of moment magnitude 7.0 with peak ground accelerations of 0.45 g, and that the fault located at the downstream toe would be activated by such an event. The presence of liquefiable layers in both the upstream shell and foundation areas led to Phase I construction activities that included constructing a stability berm, flattening the upstream dam slope and replacing riprap on the upstream face. Work took place during the late summer, fall and early winter months of 2002 and required evacuating the reservoir. Evacuating agribusiness reservoirs is dimly viewed at any time, and in 2002, Utah was already 2 years into what would turn our to be a 5 year drought.

Pockets of liquefiable embankment and fine to coarse grained alluvial deposits, downstream of the dam crest, were also identified during field studies, although it was judged that their apparent random presence did not warrant specific remedial activities associated with reducing this risk. What was of concern, downstream of the crest, was the existence of unfiltered coarse rock drains with wood stave outfall pipes. Given the nearly 100 year history of the dam, static piping of materials into the old toe drain system did not appear to represent a significant risk. However, given: (a) the close proximity to an active fault, (b) steep rock abutments, (c) the lack of significant compaction in lower, saturated embankment zones, (d) potentially liquefiable pockets in both lower embankment and underlying alluvial zones, and (e) earthquake induced alluvial material settlement; the decision was made to search for a solution that would reduce potential seismically induced piping risks to acceptable levels.

Issues

A detailed evaluation of risks and inadequacies associated with the existing downstream toe drain system revealed the following issues:
Unfiltered Existing Toe Drain System

Although project plans, specifications and construction correspondence from the early 1900’s were sometimes sketchy and occasionally contradictory, the use of any graded sand and gravel materials to envelope the specified “coarse rock” drain was never mentioned. Additionally, although generally well preserved, our experience has shown that sections of wood stave pipe do deteriorate underground. Therefore, we reasoned that there was little resistance to fine grained material piping at the external boundaries of the existing toe drain system.

Liquefiable Lower Embankment Zones and Underlying Alluvial Materials

Field studies documented the presence of liquefiable pockets in lower embankment zones and underlying alluvial materials, but nothing that would suggest these isolated areas were linked together in a sufficiently continuous enough layer to constitute a potential failure plane. Primary concerns centered on the development of excess pore pressures during a seismic event, and 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. That connections between such potentially liquefiable pockets could occur in this manner, resulting in a relatively large scale movement of materials, was considered to be a significantly more likely event.

Earthquake Induced Settlement

Although dams constructed in Utah ten to twenty years later than Piute Dam described and showed pictures of horse drawn static compactors (generally concrete cylinders), there were no indications of this kind of equipment being used at the site. In fact, most interior materials were sluiced into position using a high pressure water stream produced by a steam driven pump. Additionally, results of Standard Penetration Tests 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 was largely confined to that which could be achieved with wagon wheels and horses. Although both embankment and alluvial materials contained gravels, making volumetric strain calculations by current methods difficult; we concluded that lower embankment and foundation material settlement would be sufficient enough that bridging, transverse cracking, and void development near the steep rock abutments was likely.

Toe Drain Flow Monitoring

A further problem with the existing toe drain system was the difficulty associated with monitoring flows. Outlet pipe inverts were sufficiently depressed in elevation, that flows could not be monitored during reservoir releases because they were submerged by the down stream pool that developed during such events. 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.
Solutions

A deep drain, coupled with either the removal or isolation of the existing toe drain system appeared to be the most effective way to reduce piping risks to reasonable levels. Principal reasons leading to this conclusion and other contemplated advantages that were discussed and developed during this phase of the work included:

**Pore Pressure Dissipation Concept**

The deep drain concept evolved primarily because of our desire to arrest/control excess pore pressure development in deeper alluvial fine grained sand deposits. Results of field studies showed that such deposits occurred at or above Elevation 5990 (msl). We concluded that extending the drain to Elevation 5985 would cover most occurrences but yet keep the excavation bottom above cobble and boulder zones and within the range of bedrock elevations near both abutments.

**Existing Toe Drain Isolation Concept**

A deep drain, we reasoned, would place the existing toe drain in its influence area, thus eliminating the need to locate and excavate remnants of the old drain. Both traditional field exploration methods and ground penetrating radar techniques were used, without significant success, to definitively locate drain elements. Therefore, only those references to the drain system shown on the plans were available to guide any attempt to locate and exhume them. Additionally, the drawing showing the drain system did not appear to be an “as-built”, leaving us to further wonder about the true location and extent of in-place facilities. Our best estimate of the location of the existing drain is presented in plan view on Figure 1.

**Phreatic Surface Location**

Several years of piezometric level measurements had reasonably defined the relationship between reservoir elevation and phreatic surfaces within the dam, with the conclusion that they were marginally acceptable as they reached the downstream toe. A deep drain would enable lowering this downstream surface by several feet, which was considered to be a desirable addition to the other positive effects discussed above.

**Drain Flow Monitoring**

Given our current ability to remotely monitor almost anything on a real time basis (Mormon Crickets are now being fitted with transmitters), the ability to monitor toe drain flows – particularly immediately following seismic events- was considered to be a significant advantage. A deep drain system would not only enable our collecting real time data, but by isolating portions of the drain with individual piping systems would give us some indication of where flows were originating and, therefore, where problems might be developing. A captured drain system (i.e. in pipelines) would also enable our monitoring flows during any reservoir releases.
DESIGN ALTERNATIVES

Two design/construction concepts were eventually selected for further consideration by a process of elimination. As in most decisions related to constructed works, the balance to be obtained was that of cost versus risk. Both concepts would require temporarily increasing the downstream embankment slope, requiring excavation and replacement of existing dam materials. The relative advantages and disadvantages of each of the two alternatives, as we perceived them, are outlined below.

Open Trench Excavation Concept

This concept involved: (a) excavating an appropriately sloped deep trench to target depths, (b) dewatering the excavation as required, (c) placing and densifying drain materials, (d) placing and backfilling perforated and non-perforated pipe, and (e) replacing and compacting previously removed dam materials. The method is common practice in the construction industry with many contractors skilled in most aspects of the work.

Significant advantages, from our perspective, included the following:

- No specialized equipment or expertise would be required for excavation, drain material placement, and pipeline construction portions of the work
- During the excavation process, remnants of the old drain system could be found and exhumed, thus eliminating any further consideration/concern for this system
- All elements of the work could be visually inspected and tested

Significant disadvantages, on the other hand, included the following:

- The construction schedule would have to be delayed until as late as possible to minimize the impact of reservoir releases on this downstream construction, thus forcing earthwork into winter months
- The reservoir would have to be drawn down as far as possible, to minimize dewatering issues (in a drought year)
- Limited work areas would restrict and limit the amount of equipment that could be effectively utilized
- Our years of experience suggesting that most Rocky Mountain contractors would be challenged by expected dewatering issues

Bio-polymer Trench Excavation Concept

The bio-polymer trench concept for constructing filter/drains, is a relatively new construction concept, and has only infrequently been used in dam remediation projects. In practice, a degradable bio-polymer solution consisting of powdered guar beans, and/or synthetic bio-polymer fluids is mixed with water to produce a viscous slurry. This viscous slurry stabilizes vertical trench slopes long enough to install perforated pipe systems, geomembranes, etc. and is then displaced by filter/drain materials. Biodegradation of the
remaining slurry leaves the filter/drain clean, and capable of functioning as a very permeable groundwater receptor.

Constructing the bio-polymer trench concept involved: (a) preparing a level work platform, (b) driving sheet piling to temporarily isolate the existing drain (so that loss of bio-polymer fluids into the old drain could be minimized), (c) excavating the trench with bio-polymer fluid stabilization methods, (d) placing geomembrane/geotextile sheets in the trench (to permanently assist in isolating the existing toe drain), (e) placing and consolidating filter/drain materials, (f) placing/suspending pipelines in the bio-polymer stabilized trench, (g) deactivating bio-polymer fluids, (h) making open excavation connections to pipelines previously installed, and (i) replacing and compacting previously removed dam materials.

Significant advantages, from our perspective, included the following:

- Construction could proceed relatively independent of reservoir levels (we knew they would be relatively low during the entire year because of the drought) and reservoir releases
- The construction period would be significantly shorter due to the methods involved thus minimizing the risk of performing earthwork during winter months
- At any given slope inclination of the temporarily steepened downstream slope, the deep drain could be placed closer to the dam centerline, thus placing it in more advantageous proximity to potential liquefiable pockets/areas
- Only limited dewatering would be required when making open excavation pipeline connections

Significant disadvantages, on the other hand, included the following:

- The bio-polymer drain construction method was relatively unknown in Utah, and represented a specialized construction process and construction equipment
- The existing drain system would remain in place, with a certain level of uncertainty as to its impact on downstream drainage particularly during seismic events
- Much of the work would be accomplished without being able to visually observe, test and monitor it

Cost Effectivity Studies

Cost effectiveness studies showed that: (1) temporarily excavating the downstream slope to an angle of 1.8:1 to create a 40 foot wide work pad 80 feet below the dam crest, (2) driving temporary sheet piling to preclude bio-polymer slurry from entering the old drain system during construction, (3) constructing a 30-foot deep filter drain using bio-polymer trench techniques, (4) lining the downstream face of the trench with a 60 mil geomembrane barrier, and (5) placing a 10-inch diameter HDPE drain pipe at mid-level in the bio-polymer constructed drain, would save approximately $2 million dollars in construction costs; when compared to conventional open trench excavation methods.
The estimated cost differential was sufficiently significant that the owner elected to use the bio-polymer trench system.

**BIO-POLYMER DRAIN SYSTEM**

The bio-polymer drain plan, including the steepened downstream embankment slope, and 40-foot wide work platform, overlain on the existing toe drain is presented on Figure 2. Our plan for drain construction included excavating the 455 foot long trench in 4 nearly equal sequences. Each sequence included an isolated drain pipeline system that would enable separately monitoring flows in each of the approximately 100 foot long reaches. Ninety degree bends at Stations 11+75 and 13+75 that extended approximately 25 feet downstream from the main slurry trench constituted the exit points for each drain pipeline, and were also excavated using bio-polymer techniques. One of the potential problems we foresaw was making pipe connections with the drain operational - which it was - the moment biodegradation of the bio-polymer was complete. Constructing the pipeline bends and installing in-line pumping wells, enabled the contractor to dewater the drain upstream of any connection points and also enabled creating a seepage barrier between downstream natural soils and filter/drain materials in the bio-polymer trench. Connection conditions are shown in Photo No. 1.

From these transition points, drain lines converge at forty-five degree angles to a downstream manhole, and then continue downstream to a flow monitoring vault on a bearing that is perpendicular to the dam axis (see Figure 2).

Recognizing that drain pipelines would be at least 45 feet below the surface of the reconstructed downstream slope, cleanouts were placed at the endpoints of each sequence and extended to the surface of the downstream slope. We reasoned that these cleanouts could be used as access points to the drain system for cleaning, video observation, air sparging (if necessary), or other potential maintenance procedures.

**Typical Construction Sequence at Piute Dam**

1. **Trench Excavation:** Trench excavation was accomplished with a 3-foot wide bucket specifically designed for difficult excavations, at the end of an approximately 50 foot long “stick” attached to the boom of a Komatsu PC750 hydraulic excavator. Excavation rates for the approximately 30 foot deep trench were about 60 feet per day.

2. **Slurry Production:** Fresh bio-polymer slurry ranging in viscosity between about 60 to 122 Marsh seconds, and averaging about 80 Marsh seconds, and consisting of approximately 50 percent powdered guar bean and 50 percent synthetic polyacrylamide solution mixed with water and small quantities of other chemicals used to buffer the pH and extend slurry life was used to temporarily support trench walls. Slurry levels were maintained approximately 3 feet below the top of the trench during trench excavation and backfilling. Overnight slurry losses generally amounted to a few inches, and never exceeded 11 inches. In-trench slurry viscosity ranged from 64 to 132 Marsh seconds, with an average of about 98 Marsh seconds.
3. **Geotextile/Geomembrane Placement:** Protective non-woven geotextile panels were placed in overlapping fashion, followed by 60 mil HDPE sheets as soon as sufficient trench had been excavated and cleaned to preclude operational conflict.

4. **Bottom Layer – Filter/Drain Placement:** Bottom layer drain materials, approximately 14 feet thick were placed by tremie following geotextile/geomembrane placement and consolidated using a 2-inch diameter concrete vibrator. The vibrator was inserted the full depth of the filter/drain material at 1.5 foot intervals, in an off-set pattern approximately 8 inches from each face of the trench excavation.

5. **Drain Pipeline Placement:** Each pipeline sequence was fully assembled, including attaching weights, before being suspended in the trench. Setting/positioning these pipeline sequences (approximately 100 feet in length) in the trench was accomplished using 3 trackhoes (See Photo 2). Pipelines were held in vertical alignment by cables attached to pipeline weights and then to 4X4’s spanning the trench.

6. **Upper Layer – Filter/Drain Placement:** Drain materials were placed to depths of approximately two feet over the pipeline using a tremie to bed the pipe and secure both vertical and horizontal alignments. Following that, the tremie was used to build up a drain material slope at one end of the pipeline, after which drain materials were introduced to the trench using a front-end loader. Upper layer drain material consolidation was completed the same as described above for the lower layer.

7. **Bio-Polymer Slurry Degradation:** Pumping wells were installed during drain material placement and were used during slurry degradation phases of the work to air lift fluid from the bottom of the trench to the surface. Chemicals to assist degradation were primarily introduced at the top of the trench and then recirculated by pumping/air-lifting until a Marsh funnel viscosity of less than 30 seconds, and a neutral pH were obtained.

An overall view of bio-polymer drain construction at Piute Dam is shown on Photo 3. The foreground shows the 1.8:1 temporary downstream dam slope, sheet piling, and slurry trench operation, including drain material placement. The slurry plant can be seen in the background.

**Post-Construction Functionality**

Approximately seven months have now passed since installation of the bio-polymer drain and all elements seem to be functioning as planned. Greater than normal snowpack in the Sevier River drainage basin and recent rains have ended the drought in much of Utah, and Piute Reservoir is currently at capacity and spilling. Vibrating wire piezometer records show the phreatic surface upstream of the drain is at the target level, and drains are flowing at about the same volume as was expected. The bio-polymer drain trench appears to be the cost and technically effective solution envisioned for Piute Dam.

**Items of Potential Interest to Other Engineers**

During the course of design and construction, several items emerged that could be of potential interest to other engineers contemplating a bio-polymer drain solution to a current
problem. A number of tests and procedures, not performed on conventional projects, were attempted and completed on this project. The following items are listed and discussed in the hopes that they will aid further development and insight into the use of this geotechnical tool.

**Bench Scale Studies**

Initial bench scale bio-polymer studies were conducted during March 2002 in the Brigham Young University Civil Engineering Laboratory. Because of our limited experience with bio-polymer applications, and State of Utah Dam Safety officials concerns regarding drain material placement through the slurry (segregation) and the ability to densify drain materials in the trench, our studies centered on these two items. A 6-foot high section of 12-inch diameter PVC pipe with a valve tapped into the bottom of it was filled with slurry and then filled with representative drain materials. The test included dumping bucket loads of drain materials directly into the slurry at a relatively slow rate, with displaced slurry flowing over the lip of the pipe into a holding tub, surrounding the pipe section. The method can be best described as material pluviation, and represented what we considered to be worst case conditions for potential segregation. Degradation of the slurry then proceeded until all slurry had been broken-down/flushed from the system, and water was added to saturate the entire test column.

The column was then placed on a high frequency vibrating table, and vibrated until no further drain material settlement could be detected. A rubber mallet was then used to strike the sides of the PVC pipe column, again until further drain material settlement could not be detected. After draining water from the column, drain materials were constrained at the top, and the test column was laid on its side to enable cutting “windows” in the test column to remove representative samples for grain size distribution testing. Test results showed that only token segregation occurred during deposition. Density tests also showed that initial “pluviation” densities were very close to minimum relative density test results, and vibrated/impacted densities were close to maximum relative density test results, as was expected.

Additional tests were conducted in May 2002 to evaluate the impact of bio-polymer slurry presence/viscosity on in-place densification using ordinary concrete vibrators. Two tests were performed in 4-foot high sections of 30-inch diameter PVC pipe. The tests involved placing representative drain materials into the slurry filled test columns through an 8-inch diameter tremie until nearly full. The surface areas were then smoothed, and five points marked on the surface for optical survey measurements. Two different vibration patterns were then executed with a Vibermite VME 1-3/4 inch probe. The probe was inserted full depth and then retrieved over measured time periods. Results of these tests demonstrated that target densities (60 percent of maximum relative density) could be obtained by this method in slurry saturated drain materials.

**Test Trench Construction and Evaluations**

Given the relative success of the “bench scale” tests we elected to conduct full-scale field tests to verify the extension of laboratory tests to field conditions and the proposed method of field verifying drain material density (cone penetration methods). The field test section concept would also offer us an opportunity to test all elements of the contractors proposed procedures and time requirements for placing drain materials, placing and aligning
drain pipelines, densifying drain materials, degrading bio-polymer slurry and performing verification field permeability tests. The contractor elected to vibrate drain materials on 5 foot centers in the eastern one half of the test trench and on 3 foot centers for the other half. The vibrator was kept at the bottom of each insertion for approximately 1 minute.

A cone penetration test frame was constructed by the testing subcontractor, placed over the test trench and secured in place using a large hydraulic excavator. After penetrating the drain materials only two feet, it became very apparent that this procedure could not be used to verify material densities. At approximately four feet of penetration the cone stopped, with further efforts only resulting in buckled cone rods. The filter/drain materials were just too coarse and angular and/or too dense, due to tremie placement and vibration, to use this procedure to verify drain material density.

We then concluded to measure drain material densities by carefully excavating the test section after degradation of the bio-polymer slurry and performing nuclear density tests at various points along the drain and at 1-foot vertical intervals. Results of these density tests are presented on Figures 3 and 4. Excavating drain materials down to the top of the drain pipe with a hydraulic excavator, and then hand excavating the drain pipe, showed that drain materials fully enveloped the drain pipe including below pipe haunches. This was an important step in evaluating potential risks of voids existing in the completed bio-polymer drain.

Insitu permeability tests were conducted in open-ended wells that were installed during trench backfilling and were also used during trench development and slurry degradation. Twenty wells were installed and tested in the completed trench. The minimum required permeability coefficient was $10^{-1} \text{ cm/sec}$. Results of these tests showed drain materials were performing as expected and interstitial voids were not being plugged, or drain flows limited, by degraded slurry.

**Geotextile and Geomembrane Installation**

Specific gravities of geomembranes and geotextiles are less than that of bio-polymer slurries and thus must be weighted or otherwise inserted and then anchored to hold them in place prior to introducing drain materials. Given the limited work area available to the contractor at both ends of the trench, the contractor elected not to attempt placing membranes with the more traditional membrane frames. Overlapping geomembrane panels proved adequate for our requirements. The final procedure developed by the contractor to place geomembrane and geotextile panels seems worthy of mention because of its simplicity and effectiveness. Placement included the following steps (see Photos 4 and 5):

1. A panel was stretched across the bio-polymer slurry filled trench and one end staked into the trench bank with steel pins.
2. Waste rebar pieces were then secured to the other end of the panel (opposite side of the trench) with nylon ties that penetrated panel materials.
3. A small volume of drain materials (approximately a trackhoe bucket full) was then carefully sprinkled along the width of the panel, while the non-secured end of the panel was held by construction workers, until the center of the panel began to sink in the slurry filled trench.
4. Additional portions of the drain material filled bucket were then successively sprinkled onto the panel with the worker’s maintaining tension on their end of the sinking panel until it reached the edge of the trench, at which time it was released.

5. The shifting drain material weight then carried the panel to the bottom of the trench, serving as an anchor when it reached the panel bottom.

**Trench/Slope Stability**

Trench stability during excavation, and until it was filled with filter/drain materials, was a primary concern before and during construction. The 30 foot deep trench was located just 15 feet downstream from the toe of the 1.8 to 1, 90 foot high temporary downstream dam slope. Limit equilibrium computer stability analyses showed the combination of slope and slurry filled trench represented a factor of safety in the range of 1.25. The factor of safety of slope failure was considered adequate for the temporary slope/trench condition, but was also judged to be in the range of the development of potentially significant shear strains. Accordingly, 45 foot deep inclinometers were installed at approximately 100 foot intervals along the toe of the temporary slope to monitor any slope movement. Inclinometers were measured 3 times daily (early morning, mid-day, and late evenings) to record any slope/trench movement. No perceptible movement was recorded at any of the inclinometers during the entire construction period.

*Photo 1 – Connection at Station 11 + 75*
Photo 2 – Drain Pipe and Cleanout Installation

Photo 3 – Bio-Polymer Trench Excavation
Photo 4 – Geomembrane Placement

Photo 5 – Geomembrane Placement
Figures 3 and 4
Density - Depth Relationship for Tests Performed in Bio-Polymer Test Trenchs No. 1 and No. 2
Piute Dam

Trench No. 1

Trench No. 2