Using geosynthetics to rehabilitate Fisher Cañon Dam and Reservoir

Installation of a reservoir liner restored more-efficient irrigation to a Colorado resort

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| Prepared grouted riprap surface and deployed 22-oz/yd² cushion geotextile (with geocomposite patches in foreground).

Introduction

Fisher Cañon Reservoir is an off-channel storage facility that supplies irrigation water to the golf courses at the legendary Broadmoor Resort near Colorado Springs, Colo. The Fisher Cañon Dam was constructed in 1929 and is currently classified as a Class I high hazard structure. The dam is a U-shaped earthfill embankment up to 40ft high, impounding water against the natural hillside of Cheyenne Mountain, with interior side slopes lined with a cement-grouted riprap and the base of the reservoir covered with a compacted clay liner (CCL).

Increased leakage losses were noted in autumn of 2003 when the reservoir began losing water at a rate of about 1ft/ day, indicating an estimated loss rate of about 500 gallons per minute (gpm). A water vortex was visible in the bottom liner upon partial drawdown of the reservoir. After the reservoir was emptied, an open triangular erosion "pipe" measuring roughly 6in x 10in was found in the clay liner.

The irrigation water stored in the reservoir is critical to the ongoing operations of the Broadmoor’s 3 golf courses. However, the Colorado State Engineer’s Office (CSEO) would not allow refilling the reservoir without a complete safety review. URS Corp. was engaged to perform this review, and several alternative remediation concepts were evaluated to bring the reservoir back into safe long-term operation. During the analysis of options, URS collaborat-
vided with Colorado Lining International (CLI) to form a design-build team that could effectively complete the design and construction of the reservoir remediation.

The selected remedial design consisted of a multi-layer geosynthetic liner system, including a 22-oz. nonwoven geotextile, a 60-mil LLDPE geomembrane, and a 12-oz. nonwoven geotextile. A 12-in. soil cover was placed on top of the liner system to provide added protection against animal and environmental damage and to present a "natural" look to fit in with the surrounding residential community. This article will discuss the evaluation and selection of alternatives to bring this storage reservoir back into operation, as well as lessons learned in the construction process, and successful completion of the rehabilitation.

Key design obstacles included:
- placing the liner atop an irregularly grouted riprap surface with numerous protrusions.
- the potential for hydraulic uplift pressures between the geosynthetic liner and existing grouted riprap surface.
- providing sufficient protection of the geosynthetic liner against climatic conditions and abundant wildlife.
- protecting the soil cover from sloughing and eroding due to fluctuating reservoir levels.

Key construction difficulties included:
- limited access along half of the reservoir crest.
- significant thermal expansion causing slippage out of a portion of the anchor trench.
- sufficient anchorage of the temporary turf reinforcement mat (TRM) overlying the protective soil cover.
- time constraints in getting the reservoir back into operation.

**Dam and reservoir description**

Fisher Cañon Dam is located southwest of the Broadmoor Hotel and Resort on a natural hillside near the mouth of Fisher Cañon in Colorado Springs. Since the dam’s original construction in 1929, a prominent residential neighborhood developed in the immediate vicinity of the reservoir. Due to downstream consequences of failure, the dam was upgraded to a Class 1 high hazard structure in 2000.

The dam has a structure height of approximately 35ft, an average crest width of about 15ft, and a crest length of more than 1,000ft. The reservoir has a normal storage volume of about 50 acre-ft and a maximum estimated storage capacity of 58 acre-ft. The reservoir is an off-stream storage facility with a pool depth of about 25ft at normal operation elevation.

The dam has a downstream (exterior) slope of approximately 2H:1V (horizontal to vertical) covered with large-diameter riprap. The interior slope is approximately 3H:1V. The interior slope is covered with riprap rock with an average diameter of approximately 6-12in.

This riprap on the lower portion (i.e., below normal pool) of the upstream slope was covered with multiple applications of hand-troweled cement grout and, for practical purposes, behaved as grouted riprap. Cracks within the grouted riprap surface had been repaired by adding layers of hand-troweled cement grout and/or cracks filled with asphaltic tar. The reservoir bottom is lined with a 2- to 3-ft-thick layer of low- to medium-plasticity clay. This layer is believed to be a puddled clay placed shortly after the initial reservoir construction. Natural soils beneath the puddled clay liner.
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consist of dense, well- to poorly graded sand with variable amounts of clay, gravel, and cobbles.

The overflow emergency spillway is a riprap-lined channel located on the south side of the impoundment excavated into the natural soils. The low-level outlet works consists of 12-in. cast-iron outlet pipe with a slide-gate-controlled concrete intake structure located near the upstream toe on the northeast side of the reservoir.

Seepage investigation
Piping hole

Reservoir drawdown was initiated immediately upon identification of significant water losses. During the final stages of reservoir dewatering, a whirlpool vortex was observed approximately 20ft from the outlet works intake structure near the interior dam embankment toe.

Upon complete dewatering of the reservoir, a void ("erosion pipe") was observed at the same location of the vortex, within the dam embankment, near the interior upstream toe that was believed to be the result of the "puddle" clay piping into the underlying sands and gravel. The void was vertical near the surface and turned horizontally at a depth of about 4ft.

The "pipe" measured approximately 6-10in. both in width and height, with a triangular cross section. Black residue on the soil surface around the pipe indicated that oxidation had been occurring, which in turn indicated that the pipe must have developed over a significant period of time. The piping void was probed to a reach of about 10ft without refusal.

Seepage exit area

The seepage was found to exit in an estimated 1- to 2-acre area located on a down-gradient hillside about 1,000ft north of the piping hole. Figure 1 is a topographic map showing the location of the seepage exit area relative to the reservoir. Figure 2 shows the same area in an aerial photo.

Areas of saturated ground with thick cover of grasses, reeds, and trees were found throughout the seepage exit area. In some portions of the seepage exit area, shallow, localized slumps had developed, with tension cracks, head scarps, and hummocky topography. Gullies had formed in areas of concentrated seepage flows.

A main collection ditch about 6ft deep and 15ft wide had formed naturally along the lower margin of the seepage exit area. A temporary measurement weir was installed in the downstream portion of this ditch to monitor seepage flows during drawdown of water from the reservoir. At the time the weir was installed during the initial identification of seepage losses in October 2003, the flow at the V-notch weir measured about 200gpm. The flow at the weir decreased to about 70gpm by the time the reservoir was completely drained in December 2003, and measured less than 1gpm by the following spring when rehabilitation construction began.

The observed features in the seepage exit area likely formed over many years, indicating seepage had been occurring for a long time and flowed through the granular alluvial materials underlying the reservoir, following the surface of the bedrock, which dips in a general
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northerly direction to the seepage exit area. The alluvial materials underlying the reservoir consist of sands and gravels that range from clayey to clean sand and gravels.

At the piping hole in the reservoir floor, water had eroded materials in the lower embankment and foundation soils, possibly due to a relatively high hydraulic gradient between the reservoir water and high permeable alluvium located a few feet below the “puddle” clay reservoir lining.

Seepage flow appeared to traverse the subsurface bedrock topography rather than flow downhill due to the relatively impermeable Pierre Shale bedrock that slopes to the north and outcrops near the seepage exit area. The localized landslide features at the seepage exit area were believed to be related to sliding on the shallow Pierre Shale bedrock. Review of historical aerial photos suggests that seepage was present before 1970.

Rehabilitation design

Piping void infilling

The first measure in repairing the dam consisted of sealing the piping void. Several alternatives were considered for plugging the piping void, including installing a reverse filter, injecting a deep-seated grout plug using a pressure cement-based grout, or injecting a shallow plug using a highly expandable synthetic foam grout.

The latter alternative was selected for several reasons. It was decided that a new permanent liner would be installed to replace the deteriorating grouted riprap liner. The replacement liner would serve as the primary preventative measure to minimize future seepage from the reservoir, as will be discussed in the next section. Therefore, the key purpose of the plug would be to provide a stable subgrade for the liner with a strength requirement only to match the surrounding embankment and foundation soils.

A surficial plug was successfully installed to a length of approximately 10ft using a hydrophobic polyurethane grout that has a relatively large expansion and low shrinkage percentage. This material is an amber-colored, non-flammable liquid grout that, when contacted with water, expands and quickly cures to a flexible closed-cell polyurethane foam with moderate strength properties. The completed plug provides a continuous and stable foundation for the flexible geomembrane liner that was selected to replace the existing grouted riprap liner.

Reservoir liner

Once the reservoir was dewatered, surface cracks and signs of repairs of previous cracks were visible throughout the interior grouted riprap liner surface. Excavation of test pits through the grouted riprap liner provided for an evaluation of the liner’s integrity.
The grouted riprap liner was found to be about 1 ft thick and a sound mass requiring substantial effort to excavate. However, the extensive system of cracks within the liner prevented it from being an effective seepage barrier.

Due to the estimated difficulties and associated costs, it was decided to leave the grouted riprap liner in place and install an overlying replacement liner system. A number of liner options were evaluated.

**Liner selection**

Based upon the need to get the reservoir back in service as quickly as possible to serve the irrigation needs of Broadmoor's golf courses, a design-build approach was used to expedite the repair of the reservoir and bring it back into service before the 2004 golf season.

Colorado Lining International (CLI) was engaged to work with URS and the owner to review alternatives. A 60-mil LLDPE geomembrane was subsequently selected as the liner after considering the required combinations of strength, flexibility, puncture resistance, interface friction angle utilizing texturing options, installation robustness, availability, and cost.

**Liner cushion**

Although cracked, the dam's grouted riprap liner had retained its structural competency and would have required difficult excavation for complete removal. Therefore, the grouted riprap liner was left in place. This layer consisted of a hard, irregular surface with angular riprap protruding up to 6 in. above the nominal surface of the grout. The numerous protrusions presented a puncture risk to the geomembrane liner.

Therefore, several measures were taken to reduce the risk of puncture:
- Loose riprap and spalling cement grout was removed.
- A 6- to 12-in. soil cover was placed over the eastern and lower portions of the western side slopes. However, schedule constraints and cost considerations precluded using a soil cover over the entire subgrade. Thus, the majority of the western slope, consisting of the grouted riprap liner, was prepared for direct liner system placement by jackhammering and chiseling to reduce protrusions extending more than 2 in. above the nominal grade.
- Pieces of geocomposite (plastic open-web core wrapped in geotextile) were tacked over the reduced protrusions using mushroom-head nails. Prior to liner deployment, the nails were inspected to ensure they were secure and flush to the surface.
- A 22-oz/yd² geotextile was installed as a cushioning layer between the geomembrane liner and the grouted riprap surface. Figure 3 shows the prepared grouted riprap surface, a geocomposite cap over a protrusion in the forefront, and the deployment of the 22-oz/yd² geotextile with several more geocomposite patches visible on the far slope. A 12-oz/yd² geotextile was placed overlying the geomembrane liner to provide protection and an increased frictional resistance during placement of the soil cover.

**Liner drainage features**

It was speculated that seepage through the grouted riprap liner was via preferential flow paths through cracks, while the majority of the grouted surface provided a relatively low permeability barrier. As a result, there was a perceived risk that the 22-oz/yd² geotextile cushion layer would act as a drain layer between 2 low-permeability barriers for any pinholes or defects in the geomembrane liner and create potential uplift pressures during times of low reservoir levels.

In addition, several seepage areas emanating from near the interior embankment toe were observed once the reservoir was drained. These seepage
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points were interpreted to have been associated with areas of the embankment and natural slopes that had previously been wetted due to leakage through the grouted riprap liner. In response to this concern, 9 1-way pressure relief check valves were installed through the geomembrane. The relief valves were embedded within sand sumps constructed at the upstream toe immediately above and in contact with the 22-oz/yd² geotextile around the interior perimeter of the reservoir.

In addition, a geocomposite strip drain was welded to the 12-oz/yd² geotextile overlying the geomembrane and daylighted through the soil cover. This drain was installed to relieve excess water pressure accumulated within the 12-oz/yd² geotextile beneath the soil cover on the side slopes of the reservoir during drawdown.

**Soil protection cover**

LLDPE geomembranes are generally considered to have adequate resistance to degradation induced by ultraviolet (UV) exposure and are often used without a protective cover. However, the abundant local wildlife in the Fisher Cañon area, including bear and deer, frequent the reservoir as a watering hole. An unprotected liner would be at risk to frequent and severe punctures and tears from animal hooves and claws. Several options for providing protection against such damage were considered, including a sacrificial liner, a gravel-filled geoweb, and an unreinforced soil cover.

Past evidence indicated that animals can lose their footing on liner material and may not have sufficient traction to escape the pool. In addition, local residents, including owners of homes adjacent to the reservoir, gave great importance to the aesthetics and maintenance of a natural-looking environment. For these reasons, plus cost considerations, a 12- to 18-in. soil layer was selected as the preferred protective cover.

**Soil cover erosion protection**

Calculations of static stability indicated an adequate factor of safety against sliding of the soil cover based on estimates of interface friction an-
any clogging of the irrigation system. Figure 4 shows a schematic of the dam and liner cross section.

Construction difficulties and remedies

Liner deployment

Standard liner deployment methods generally consist of deploying geosynthetics using a forklift at the crest and rolling the panels downslope. Access limitations along the western crest of the reservoir due to existing trees, topography, and private home sites prevented using standard methodologies.

The 22-oz/yd² geotextile was rolled manually downslope. Once the 22-oz/yd² geotextile was in place, the 60-mil geomembrane was deployed. Due to the weight of the membrane, a wheeled forklift was driven directly atop the 22-oz/yd² geotextile on the lower, less steep, portions of the western interior slope. The boom on the forklift was then extended and the remaining roll was manually rolled upslope. Immediately following deployment of each panel, the geomembrane was pulled back where the forklift drove to inspect the 22-oz/yd² geotextile for damage. The overlying 12-oz/yd² geotextile was manually rolled downslope and no equipment was driven atop the geomembrane.

Anchor trench slippage

During one weekend, at a time of no onsite activities, the geomembrane panels placed up to that date along the western slope experienced significant thermal expansion and contraction. As a result, a length of approximately 400 ft of geomembrane pulled out of the anchor trench that was weighted with sandbags, and it slipped approximately 2-5 ft down the interior reservoir slope.

Access limitations along the western slope prevented heavy equipment from accessing the top of the slope to pull the geomembrane panel back in place. Therefore, panel extensions were welded on the end of the pulled-out panels, resulting in a horizontal extrusion seam along the western crest.

In consideration of expected tensile stresses in this location, a cap strip was welded to provide secondary support for the primary connection weld. The cap strip was constructed of a full panel width of geomembrane installed perpendicular to the slope along the crest. The upper seam of the cap strip was secured in the anchor trench and the lower seam of the cap strip was located several feet below normal pool to protect against thermal exposure.

Soil cover placement

A 12-in. soil cover was placed to protect the liner system from environmental exposure and to provide enhanced aesthetics. Cover soil material consisted of a clayey sand to sandy clay from a nearby excavation. The material was hand-picked to be free of debris and any angular particles greater than approximately 1.5 in. and rounded particles greater than approximately 3 in. In areas designated for haul traffic during soil cover placement, the thickness was temporarily maintained at 3 ft and then later graded to the design thickness of 12 in. The soil cover material was placed from the toe and pushed upslope using a track dozer with an estimated ground pressure of approximately 50 lbs/in².

TRM anchorage

Anchorage of the TRM was a concern. Standard 6-in. staples were tried at a smaller-than-typical spacing of 2 ft, in consideration of the buoyant forces, with inadequate results—the saturated soil cover did not provide adequate anchorage for the staples. Numerous sections uplifted and floated on the reservoir surface and were cut off.

The TRM was intended to protect the slope from erosion within the range of typical reservoir fluctuations and did not extend to the reservoir bottom. Therefore, anchoring the TRM in a toe trench was not feasible. However, alternate methods of anchoring or weighting the lower end of the TRM, such as tying sandbags or tires, would have better secured the TRM than the standard method of staples.

Outcome

Rejuvenation of Fisher Cañon Reservoir was successfully completed on time and within budget. The reservoir was filled and in full operation in time for required golf course irrigation. During the past three years of liner performance, no reservoir losses have been recorded. A permanent fiberglass weir box installed within the conveyance gully at the seepage exit area measures negligible flows.

Conclusions

Gradual seepage losses are sometimes difficult to detect, especially in cases where the seepage exit point is not in the near vicinity of the dam. Gradual seepage can lead to piping developing into a void that may suddenly cause a rapid loss of reservoir pool. This sudden increase in seepage losses increases the risk of overall...
dam stability and could potentially lead to a breach.

The use of geosynthetics in dam and reservoir rehabilitation can save time, money, and most of all, can provide a solid engineering solution to the safety issues facing earth dams experiencing seepage losses.

By using a design-build approach to install this geomembrane lining system, the Fisher Cañon Reservoir project was completed on time and within budget. The design-build approach allows a compressed schedule that generally correlates to cost savings for the owner. From the owner’s perspective, the greatest advantage of utilizing a design-build approach was the time savings in restoring the reservoir into effective service in time for essential irrigation needs.

This project also demonstrated that an experienced design and construction team can instill trust with the owner, which is crucial for efficient implementation of the repair and for efficient approvals from regulating agencies.

Project Highlights
Fisher Cañon Dam & Reservoir
Location: Colorado Springs, Colo.
Project timeline: May 19–July 16, 2004
Owner: Broadmoor Development Corp.
Engineering/Design: URS Corp.
Distributor/Design:
Colorado Lining International
Geomembrane: GSE Lining Technology Inc.
Geotextiles: Propex
TRM: North American Green C350
Grouting: Do Neeff Hydro Active Combi Grout

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