

## Surface impoundment rehabilitation

In a previous Designer's column (April 2002), the second author presented an evaluation of the failure of a surface water reservoir. This reservoir had failed during post-construction hydrostatic testing and had not provided a single day's service for the water district. As detailed in that article, the failure was the result of a combination of unstable subgrade soils and design assumptions that did not manage seepage through the geomembrane and steel battening system. At the time Red Mesa Consulting Inc. was retained to provide remedial design services, the water district was approximately two years behind schedule in its plans for expansion. To further aggravate circumstances, water supply reservoirs upgradient were experiencing severe decreases in storage because of persistent drought conditions. This article presents the rehabilitation of the reservoir that is now in service and functioning in accordance with the design.

### Key redesign decisions

Recall that the original pond liner system consisted of a single layer of HDPE geomembrane with slopes that transitioned to concrete walls and fastened using steel battening. The original geometry of the impoundment was irregular with abrupt changes and a slope of 1:1 in the vicinity

of the inlet pipe. The concrete walls and floor were extensively cracked after the failure and were unable to contain water. Further, the HDPE liner had deteriorated from exposure to high winds. It was decided to remove the HDPE liner and steel battening early on to identify the degree of damage from the catastrophic failure and subsequent weathering.

The first step in the rehabilitation was the evaluation of different design options with consideration to cost and schedule. The extreme option was complete removal of the current liner system and impoundment berms. This would eliminate the unstable subgrade soils, but would be the most expensive and time consuming option. Instead, it was decided to use the existing berms and design a liner system that would ensure the subgrade remain unsaturated.

The rehabilitation had to maintain the embankment and foundation soils in an unsaturated condition by keeping the material isolated from water infiltration. The design incorporated two relatively impervious liners and a seepage collection system for redundancy to ensure an unsaturated environment. The double liner system with seepage collection provided the necessary safeguards for the intended use of the pond. Further, the existing geometry of the pond was simplified, and abrupt changes in lines



**Photo 1.** The completed access ramp and base clear the way for the geosynthetic redesign of the structure.

and grades were eliminated. This allowed for a simpler liner system that made construction easier. It should be noted that the authors do not recommend the use of a steel battening system where it will be subject to even a minor fluid head. Eliminating the steel battening and concrete containment basin meant that the geosynthetic liner would be continuous throughout the impoundment's interior.

### Revised liner system

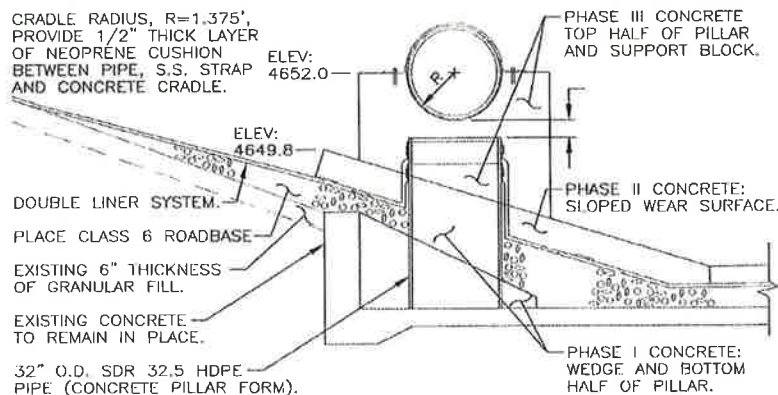
Given that a repeated failure of the pond would be catastrophic particularly with respect to the client's schedule, the revised liner system was designed to provide both performance monitoring and redundancy. The revised liner system incorporated the following components (bottom up):

- geosynthetic clay liner,
- 40-mil PVC secondary liner,
- geosynthetic drainage composite, and
- 60-mil HDPE primary liner.

Dissimilar liners were selected to improve the redundancy of the system. The HDPE liner offers superior UV protection and resistance to typical exposure damage. The PVC liner offers superior biaxial elongation in case localized erosion and deformation occurs. The geosynthetic clay liner was selected in lieu of reconstructing the embankment with materials that meet filter criteria.

At the onset of the project, it was decided to stabilize the foundation under the cracked concrete floor using low-pressure

**Figure 1.** Inlet pipe support detail.



grout placement. The majority of the grout was placed near the area of failure and along trenches originally intended for dewatering the sediments. Additionally, road base was placed to the height of the concrete stemwall to eliminate the abrupt change in geometry; however, filling the bottom reduced capacity. To offset the loss of storage volume, the embankment was raised an average of 2 ft. (60 cm). **Figure 2** shows the revised liner system placed over the failed reservoir floor. Sub-drain lines were retained and currently drain the granular soil placed above the original concrete floor. In addition, the geosynthetic seepage collection system reports to these same lines and a weir was added to the combined outlet of the sub-drain lines to allow the accurate quantification of the liner performance. The

failed concrete bottom now provides another level of liquids collection to protect the unstable subgrade.

### Pipe penetrations

The failed design incorporated over a thousand feet of steel battening to connect the original geomembrane liner to the concrete walls. This connection could not be tested for continuity and was subjected to approximately 20 ft. (6 m) of head. The use of a continuous liner limited the potential leakage points to 10 locations where either pipes or pipe supports penetrated the composite liner. Given that 30-in. (76-cm) pipes feed and drain the reservoir, the handling of the pipe penetrations was considered critical to the success of the reservoir.

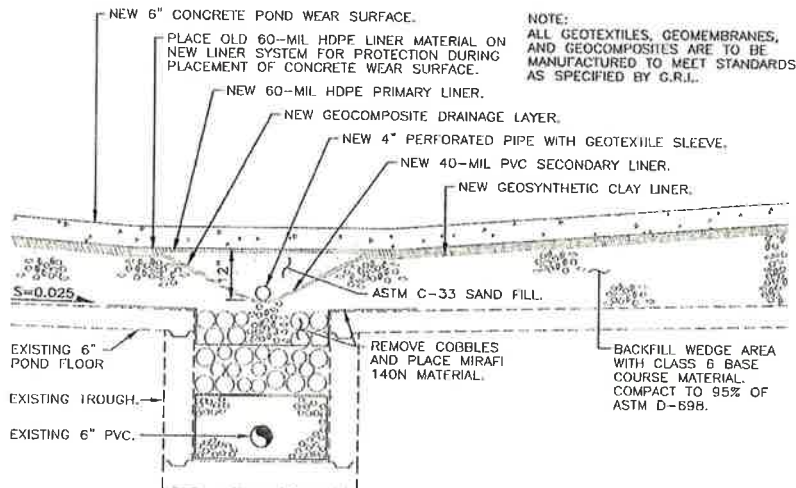
With the exception of the inlet pipe, all of



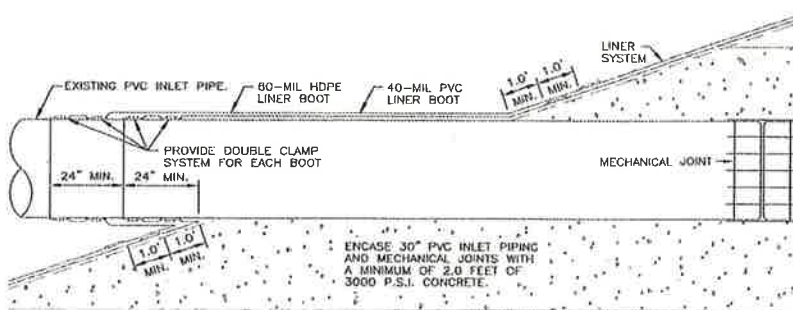
**Photo 2.** The rehabilitated reservoir is finally able to begin serving the water district.

the liner penetrations were made using a neoprene cushion and stainless steel straps encapsulated in concrete. **Figure 2** shows how the new liner was integrated into the inlet pipe support columns. The penetration of the liner was protected from exposure and direct contact with the water in the reservoir by more than 6 in. (15 cm) of concrete.

However, the large 30-in. inlet pipe penetration was not protected by concrete. As shown on **Figure 3**, the performance of the pipe boots around the pipe was verified by using two neoprene cushion and stainless steel strap seals on each liner boot such that they could be pressure tested. The pipe was also placed in a concrete block to limit its movement and any potential erosion near the pipe.



**Figure 2.** Liner system detail.



**Figure 3.** Inlet pipe boot detail.

### Access to pond interior

To allow the water district access to the interior of the reservoir for clean out, a concrete ramp and base slab were placed on the liner system. A 12 oz nonwoven was used as a cushion between the concrete and the underlying liner. This also provided for drainage from beneath the concrete access system. The access ramp into the reservoir bottom is supported by both adequate interface frictions in the underlying liner system and from buttressing by the concrete base slab. **Photo 1** shows the completed concrete access ramp and base. Note that "Jersey" style barriers were incorporated at the perimeter of the concrete base liner to protect the exposed HDPE side slope liner from damage during future sediment clean out operations.

In addition to the need for access to the pond for equipment, the water district required a drain located at the low point of the concrete base slab. A 16-in. (40-cm) PVC pipe with a sliding gate valve was pro-



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vided at the base of the reservoir. The penetration seals for this pipe were also cast into the new concrete base slab. This pipe provided a drain in the event the water district needs to use high pressure hoses to clean out river sediment.

### Construction

Reconstruction of the reservoir began in late July 2002 by Nielsons SKANSKA. The liner system was installed by Simbeck & Associates. Redesign, construction oversight and CQA for the rebuild was provided by Red Mesa Consulting Inc. Construction was completed in early November 2002. The rebuild of the impoundment cost the water district approximately \$534,000. The Colorado State Engineer's Office granted acceptance of construction on 10 January 2003. Photo 2 shows the reservoir full and in service today.

### Lessons learned

The failure and subsequent redesign of this reservoir points out several important lessons to designers:

- Build earthen reservoirs on stable foundation soils and with suitable materials.
- If construction materials do not meet filter criteria, than engineered seepage control measures must be incorporated into the design such that the controls will not damage the system or the underlying soil support for the system.
- Avoid the use of steel battening liner terminations below liquid levels. If steel battening must be used below the liquid level, provide encasement of the batten strip or use double batten strips to allow pressure testing of the seal.

With the surface impoundment placed back in service the only remaining activity is the inevitable litigation that follows a failure. It is unfortunate that so many of our best lessons must come at such expense. **GFR**

### Reference

Richardson, Gregory N. 2002. Surface Impoundment Design Goals. *Geotechnical Fabrics Report*. v 20, no 3.

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