Multiple Methods to Control Reservoir Seepage

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ABSTRACT
Miller Reservoir and Dam is a 43-ft-high (13-m-high), 5,000-ft-long (1,524-m-long) dam located along the South Platte River north of Denver, CO. The reservoir is located at the site of a previous gravel mine. The capacity of the original gravel pit reservoir was about 800 acre-feet (986,800 m³). By constructing a perimeter embankment and soil-bentonite cutoff wall and mining material within the limits of the reservoir, the storage was increased to over 2,000 acre-feet (2,467,000 m³). This additional storage is an integral part of the water management system of Denver Water, which services 1.3 million customers and is Colorado’s oldest and largest water supplier. Because of site constraints and property boundary limitations, the seepage barrier for the dam foundation included the combination of about 6,600 ft (2,012 m) of soil-bentonite cutoff wall with about 1,400 ft (427 m) of core trench extending into bedrock. The embankment consisted of three different typical dam sections that made use of available onsite materials for construction. Four distinct methods to connect the clay core of the embankment with the different seepage-control measures were designed and incorporated into the project. Vertical connections between the clay core, soil-bentonite cutoff wall, and bedrock were also designed and installed adjacent to the outlet works tower. This paper will present the different types of seepage control, incorporation of the embankment internal zoning with the seepage-control methods, and material utilization for dams with multiple seepage barriers.

INTRODUCTION
Due to their relatively low cost and simplified permitting, conversion of gravel pits into water-storage reservoirs has become an increasingly popular way to store water along the Colorado Front Range. Their popularity is demonstrated by the 15 gravel pit reservoirs along a 15 mile (24 km) section of the South Platte River corridor northeast of Denver, CO. The Miller Dam and Reservoir Project was developed by Denver Water to augment their existing water management system by converting a gravel mine into a water-storage facility. The Miller Dam and Reservoir site is located as shown on Figure 1.

Project Description
Prior to construction of the dam and reservoir, the site consisted of an unlined gravel pit with the potential to store approximately 800 acre-feet (986,800 m³) of water below the existing ground surface. The land had been mined by a local aggregate company, and the site was then purchased by Denver Water. An adjacent, unmined property south of the gravel pit mine was also acquired by Denver Water. A soil-bentonite cutoff wall was constructed around the perimeter of both properties. During design of the soil-bentonite cutoff wall, Denver Water performed an evaluation of the site and concluded that a perimeter embankment dam could increase storage to about 2,000 acre-feet (2,467,000 m³). The design of the soil-bentonite cutoff wall was performed by another firm (Kumar and Associates) and was coordinated with the design of the embankment to provide continuous seepage control around the reservoir. The Colorado Office of the State Engineer reviewed and approved the embankment design.

A 5,000-ft-long (1,524-m-long) embankment dam, up to 43 ft (13 m) in height, was constructed around
the north, west, and south sides of the site. The embankment was designed and constructed with three different internal geometries to address different project constraints, and utilize available onsite materials. An erosion berm was constructed along the east side of the site and provided an area for excess and miscellaneous materials to be placed. These areas are shown on Figure 2.

Fill materials were obtained from onsite sources. Alluvial clays and granular materials were typically derived from unmined areas south and east of the existing gravel pit. Clayey materials were also derived from claystone and siltstone bedrock, which was excavated from the reservoir bottom and along the erosion berm.

Regional Geology

Miller Reservoir and Dam is located in the Colorado Piedmont section of the Great Plains physiographic province, which is characterized by east-tilted surfaces formed by deposition of sediment eroded from the

Figure 1. Satellite photograph of South Platte River corridor in northeast Denver metropolitan area (Digital Globe, 2006). Note: 1 mile = 1.609 km.
uplifting Rocky Mountains in Early Tertiary time, beginning about 65 million years ago. This upraised region is now being eroded by many east-flowing rivers, which expose older materials (USGS, 2000, 2007).

Site Geology

The subsurface generally consisted of up to 40 ft (12 m) of Holocene-age post–Piney Creek and Piney Creek alluvium overlying Cretaceous age Denver Formation bedrock (Trimble and Machette, 1979). Generally, alluvial clays constituted the top 1.5 to 13 ft (0.5 to 4 m) of alluvium and had plasticity indices (PI) ranging from 7 to 29. The remaining alluvium was typically sand and gravel containing less than 12 percent fines. Denver Formation bedrock was composed mostly of claystone, with lenses of siltstone and sandstone. Bedrock was relatively soft and was excavated and processed to a consistency similar to soil by mechanical means. Claystone and siltstone of...
the Denver Formation generally had between about 51 and 99 percent fines with PI values between 40 and 58. Site geology is shown on Figure 3.

Figure 3. Site geology and generalized section. Geologic map and descriptions are from Trimble and Machette (1979). Generalized section is approximate and for conceptual purposes only. Note: 1 US ft = 0.3048 m.

Design of Gravel Pit Reservoirs in an Urban Environment

Similar to the more traditional dam and reservoir project, the ultimate goal of this project was to maximize water storage while minimizing construction costs. To minimize cost, the design needed to utilize onsite materials for embankment construction. To maximize storage, the design needed to allocate as much area as possible for water storage. However, unlike more traditional dam and reservoir projects, gravel pit reservoirs that are constructed in an urban setting typically have tighter property boundary restrictions for the dam footprint, and some borrow
Table 1. Onsite materials used for fill zones.

<table>
<thead>
<tr>
<th>Fill Material</th>
<th>Onsite Material/Geology</th>
<th>Material Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zone 1</td>
<td>Claystone and siltstone derived from Denver</td>
<td>Low permeability</td>
</tr>
<tr>
<td></td>
<td>Formation bedrock</td>
<td>Minimum 50 percent passing a No. 200 sieve</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Minimum PI of 12</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Maximum particle size of 1 in.</td>
</tr>
<tr>
<td>Zone 1A</td>
<td>Alluvial clay derived from post–Piney Creek and</td>
<td>Low permeability</td>
</tr>
<tr>
<td></td>
<td>Piney Creek alluvium</td>
<td>Filter compatible with zone 1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Minimum 35 percent passing a No. 200 sieve</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Minimum PI of 12</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Maximum particle size of 1 in.</td>
</tr>
<tr>
<td>Zone 2</td>
<td>Alluvial sand and gravel derived from post–Piney</td>
<td>Free draining</td>
</tr>
<tr>
<td></td>
<td>Creek and Piney Creek alluvium</td>
<td>Maximum 15 percent passing a No. 200 sieve</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Maximum PI of 4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Maximum particle size of 6 in.</td>
</tr>
<tr>
<td>Zone 3</td>
<td>Alluvial sand and gravel derived from post–Piney</td>
<td>Free draining</td>
</tr>
<tr>
<td></td>
<td>Creek and Piney Creek alluvium</td>
<td>Filter compatible with zone 1A</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Maximum 15 percent passing a No. 200 sieve</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Maximum PI of 4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Maximum particle size of 2 in.</td>
</tr>
<tr>
<td>Miscellaneous fill</td>
<td>All available onsite materials</td>
<td>Maximum particle size of 9 in.</td>
</tr>
</tbody>
</table>

1 in. = 2.54 cm.

Figure 4. Looking in upstream direction at core trench excavation for the north embankment foundation. Note that the left portion of core trench is being cleaned with compressed air.
materials have been disturbed by previous mining activities. The following were some of the major project considerations for the design of Miller Dam and Reservoir:

- The site was located in an urban environment; there was development on the north, east and south sides of the reservoir and the South Platte River on the west side. This limited the alignment of the soil-bentonite cutoff wall and subsequent embankment.
- Borrow sources were limited to within the project site, which was about 65 acres (236,000 m²), of which about 32 acres (129,500 m²) were unmined. Over 733,000 cubic yards (560,400 m³) of fill were required for the embankment and erosion berm.
- Embankment internal zoning needed to utilize onsite materials for seepage control, and adjacent materials in the embankment needed to be filter compatible to eliminate the need to import expensive filter materials.
- Materials not suitable for embankment construction were to be used onsite in a manner that would increase storage volume but also meet the design requirements.

Embankment Design

The selection of embankment internal zoning was based primarily on seepage control and filter compatibility between adjacent materials. The width of internal embankment zones was influenced by the availability of various onsite materials.

Based on the results of a filter compatibility analysis (NRCS, 1994), the alluvial clay materials were filter compatible with alluvial sand and gravel materials that were well graded, had a $D_{15}$ less than or equal to 0.03 in. (0.7 mm), and had a maximum particle size of about 2 in. (5 cm). The clay borrow derived from bedrock was filter compatible with the alluvial clay, but not the alluvial sand and gravel.
Materials used for the internal zoning of the embankment are listed in Table 1.

To address the design criteria and the filter compatibility of the onsite materials, three different embankment configurations were developed for the north, the west, and the south embankments. Four distinct methods to control seepage were designed. All of the seepage-control methods needed to incorporate flexible connections because two different foundation materials would be encountered (alluvial sand and gravel and bedrock). The details of each embankment section are described next.
Figure 7. Fill zones in west embankment. Downstream side is on left side of photograph.

Figure 8. Slip joint connection along south embankment foundation. Downstream side is on left side of photograph.
North Embankment

The north embankment could not be located over the existing soil-bentonite cutoff wall for two reasons: (1) there was not enough property for the embankment footprint, and (2) the soil-bentonite cutoff wall could not be aligned with the embankment because of the previous mining activities. The embankment was located upstream (inside) of the cutoff wall and founded on bedrock. The seepage control consisted of a central clay core keyed at least 4 ft into bedrock (Figures 4 and 5) with a minimum bottom width of 20 ft (6 m) (USBR, 1987). The majority of the core was composed of Zone 1; the downstream portion of the core was composed of zone 1A; and the downstream shell was zone 3. Figure 6 includes a cross section of the north embankment.
West Embankment

The west embankment was located so that the core of the embankment would coincide with the soil-bentonite cutoff wall. During construction of the cutoff wall, a 5-ft-thick (1.5 m) by 20-ft-wide (6 m) section of zone 1A was placed prior to installation of the cutoff wall. The cutoff wall was installed through about the center of the zone 1A fill. The embankment was then constructed over and connected into the existing zone 1A fill material. The purpose of the zone 1A fill was to create a "slip joint" in the embankment, which maintains overlap between the top of the soil-bentonite cutoff wall and the bottom of the embankment core. When the soil-bentonite cutoff wall settles, the settlement will occur within the core of the embankment and will not create a void below the core and a seepage pathway through the embankment. A cross section of the west embankment is included on Figure 6. Internal zoning of the west embankment is also shown on Figure 7.

South Embankment

The south embankment was located in the unmined portion of the site. The embankment was a homogenous zone 1 fill located over the soil-bentonite cutoff wall. Similar to the west embankment, a "slip joint" connection between the embankment and soil-bentonite cutoff wall was also used in the south embankment, as shown on Figure 8. A 3-ft-thick (1 m) layer of zone 1A was placed between the zone 1 and alluvial materials downstream of the cutoff wall for filter compatibility through the embankment. A cross section of the south embankment is included on Figure 6. The north, west, and south embankment sections incorporated two of the four seepage-control details, (1) embankment clay core excavated into bedrock, and (2) embankment clay core connected to the existing soil-bentonite cutoff wall. The other two seepage-control details were located at the northwest corner of the site where the core trench and cutoff wall needed to connect and at the outlet works. Both are described next.

Northwest Corner

Construction of the seepage connection between the core trench in the north embankment and the soil-bentonite cutoff wall in the west embankment consisted of the following:
excavating the core trench to about 16.5 ft (5 m) from existing soil-bentonite cutoff wall;

placing core materials to about 17 ft (5 m) above the top of bedrock; and

excavating a final soil-bentonite cutoff wall through the clay core and core trench about 1 ft into bedrock for a total of about 5 ft (1.5 m) below the top of bedrock. The final cutoff wall then extended across the portion of the embankment without a seepage cutoff and connected into the existing soil-bentonite cutoff wall as shown on Figures 9 and 10.

Outlet Works

Construction of the outlet works required a penetration through the existing soil-bentonite cutoff wall. A temporary braced excavation was used to support the existing soil-bentonite cutoff wall and excavation slopes during construction of the outlet works. After the outlet works was constructed, the excavation was backfilled with the appropriate embankment materials to about 27 ft (8 m) above the top of bedrock. The braced excavation was removed, and 5-ft-diameter drilled shafts were excavated at the two intersections of the braced excavation and the existing soil-bentonite cutoff wall (Figure 11). The shafts were cased, extended at least 5 ft (1.5 m) into bedrock, and backfilled with soil-bentonite. The soil-bentonite backfill provided a flexible joint and connection between the existing cutoff wall and the core materials adjacent to the outlet works. A profile along the soil-bentonite cutoff wall with the drilled shafts is shown on Figure 12.

SUMMARY

The design of Miller Reservoir embankment required multiple seepage-control methods and embankment sections. The design utilized available onsite materials to maximize storage and reduce costs. A
major cost savings resulted from the use of onsite materials that were filter compatible and from designing internal zoning so that imported or processed filters were not necessary. Because of differing foundation conditions, flexible connections were used to allow for settlement between the different foundation materials and maintain long-term seepage control.

REFERENCES


Figure 12. Construction of 5-ft-diameter soil-bentonite drilled shaft connections. After removal of sheet pile excavation supports, the shaft is centered on the location where the sheet pile supports intersected the soil-bentonite cutoff wall. Downstream side is on left side of photograph.