Construction of the Hazeltine, Road Runners Rest II and Brinkmann-Woodward Gravel Pits, Denver, Colorado


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The design and construction of the soil-bentonite liner for the Hazeltine, Road Runners Rest II and Brinkmann-Woodward Gravel pits (Hazeltine) involved a 15- to 63-foot-deep by 3-foot-wide by about 3-mile-long cutoff trench filled with a soil-bentonite backfill that would combine three existing sand and gravel mines into one water storage facility that will ultimately provide Denver Water with 5,100 acre feet of storage along the South Platte River.

The design and construction of the reservoir was accelerated to accommodate construction of 120th Avenue. The new roadway crosses through the Brinkmann-Woodward and Road Runners Rest II pits, and requires up to 15 feet of fill to be placed above the soil-bentonite cutoff trench.

The factors affecting liner construction included a tight schedule and ongoing mining operations that constantly changed site conditions throughout design and construction.

The team of GEI Consultants, Inc. (GEI), Denver Water, and Envirocen, the contractor, quickly adapted an interactive approach to meet the challenges of construction at a site that changed daily, including modifying the alignment and placing over 200,000 CY of fill to create a working platform for construction of the trench. The team also had to respond to unforeseeable site conditions, like a 450-foot-long, 12-foot-deep section of concrete that had to be removed for liner construction.

This paper discusses the construction challenges of the Hazeltine, Road Runners Rest II, and Brinkmann-Woodward gravel pit liner.

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(3) James Weldon, Denver Water  Role on Project: Project Manager
Introduction

The Hazeltine, Road Runners Rest II, and Brinkmann-Woodward gravel pits were lined with a 14,800-foot-long soil-bentonite cutoff trench to meet the requirements of the Colorado Office of the State Engineer (SEO) leakage criteria for a lined water storage facility. Construction was completed between September 2003 and January 2004.

The project is located between Old Brighton Road and the South Platte River from about 112th Avenue to 120th Avenue in Commerce City, Colorado. Denver Water was originally planning to convert two of these pits, the Hazeltine and Road Runners Rest II Gravel Pits, into lined water storage facilities. GEI has been conducting geotechnical explorations and feasibility work since 1998 to support Denver Water in this project. Recently Denver Water added the Brinkmann-Woodward Gravel Pit to the project as part of an agreement with Adams County and the Colorado Department of Transportation (CDOT). Adams County is upgrading 120th Avenue. As part of these upgrades, 120th Avenue will be realigned to cross the South Platte River along the northern edge of the Road Runners Rest II Gravel Pit, and a new road embankment will be constructed along the northern edge of Road Runners Rest II Gravel Pit and across the adjacent Brinkmann-Woodward Gravel Pit. The embankment will require fills up to 15 feet above the top of the cutoff trench. The soil-bentonite cutoff trench provides Denver Water with a lined storage reservoir and will aid CDOT and its contractor in dewatering the Road Runners Rest II, and Brinkmann-Woodward pits for construction of roadway fills required for 120th Avenue.


Design

Design for the soil-bentonite cutoff trench was originally scoped to be performed within a short schedule. Two milestones for design were established to allow for the project to be bid with initially limited information. The original schedule for design is shown on Figure 1.
Figure 1 - Schedule
The key items for design were: 1) establishing the horizontal alignment, 2) establishing the vertical alignment (depth excavated into bedrock) and 3) providing construction drawing and specifications for bidding purposes. Primary challenges to accomplishing design were:

- Accelerated schedule
- Early bid packages with addenda
- Changing site topography during design
- Inability to modify exterior slopes
- Establishing a safe zone for construction of the cutoff trench

The accelerated design schedule would be accomplished by designing the horizontal alignment of the cutoff trench during the final design field exploration program. The vertical alignment would then be designed after data from the field exploration program was reduced; concurrently Denver Water would review the horizontal alignment and start the bidding process for the construction. The bidders would then be provided the vertical alignment early in bidding as an addenda to the issued for bid drawings and specifications.

The accelerated schedule was lengthened during design due to property acquisition problems encountered by Denver Water. This allowed GEI to design the project in one phase and provided Denver Water with a cost savings in the design process.

**Horizontal and Vertical Alignment Design**

The horizontal alignment of the cutoff trench, in general, is between a mined gravel pit with varying slopes between 0.8H:1V (horizontal to vertical) and 4H:1V and either the Bull Seep, South Platte River, or Old Brighton Road, as shown on Figure 2. The topography available during design was changing on a regular basis in the Road Runners Rest II gravel pit due to ongoing mining operations. The location of the cutoff trench was aligned toward the outside edge of the property to increase the quantity of sand and gravel available for mining and to provide a working/mixing platform along the gravel pit side of the project. Items that controlled the horizontal alignment are as follows:

- Along Old Brighton Road property offsets and the required room for placement of the excavator.
- Along the Bull Seep and South Platte River existing slope configurations.
Two-dimensional stability analyses were performed for both interior and exterior slopes. Design factors of safety for interior slopes of 1.3 and 1.5 were used for mined (temporary scenario) and unmined (long-term scenario) interior slopes, respectively. The design factor of safety (FOS) for exterior slopes was 1.5.

The methodology used to develop the horizontal alignment design for the soil-bentonite cutoff trench involved identifying the limits of the safe crest width needed to provide an adequate FOS against critical failure surfaces from intersecting the installed cutoff trench. The procedure used is shown schematically on Figure 3. Each representative slope cross section was analyzed for a minimum FOS and the critical failure surface was obtained. This critical failure surface was used to identify the zone of the slope that would be potentially unstable. The alignment was developed by placing the soil-bentonite trench outside this zone of potential instability. Analysis of the interior slope provided the “interior offset.” Similarly, analysis of the exterior slope provided the “exterior offset.” The distance between the two offsets provided the “safe zone” in which the soil-bentonite cutoff trench could be installed.

![Figure 3 - Stability safe zone.](image)

In some locations, such as between Stations 40+00 to 64+00, Stations 76+50 to 79+25, and Stations 80+50 to 84+50 it was concluded that there was not sufficient crest width to allow installation of the trench in a safe zone. In these areas, because the exterior slopes could not be modified, stabilization fill needed to be placed along the interior side slopes. The locations of the stabilization fill were based on the existing topography and observations during site visits.

Stabilization fill consisted of on-site sand and gravel with less than 10 percent fines. Stabilization fill was considered to be placed by end dumping from trucks where the fill is below the water level in the gravel pit and placed and compacted in 8- to 9-inch lifts above the water level, with an exterior slope of about 2.5H:1V.

The vertical alignment of the cutoff trench was designed to minimize the depth of the cutoff trench excavated into bedrock, but provide an adequate FOS against the infiltration of water into the reservoir to meet the SEO leakage criteria for a lined water storage facility.
Seepage analysis was performed for the maximum expected seepage conditions, which occur when the pit is empty and the groundwater level outside of the pit is at its highest level. The flow rate (seepage) through each representative section is the flow rate through the cutoff trench above the top of bedrock and the flow rate through bedrock and the cutoff trench below the top of bedrock.

The calculated SEO maximum allowable total Design Standard leakage rate into the Hazeltine, Road Runners Rest II, and Brinkmann-Woodward Reservoir is 156 gallons per minute (gpm) and the total Performance Standard leakage rate is 468 gpm.

The methodology for the seepage analyses was to develop representative cross sections for the site with thicknesses and hydraulic properties for surficial and bedrock materials. The soil-bentonite cutoff trench was modeled as a 2.5-foot-wide layer extended from the ground surface downward into bedrock.

Thicknesses of materials were derived from boring logs. Hydraulic conductivities were based on 1) packer permeability tests conducted in the borings, 2) published correlations between hydraulic conductivity, soil classifications, and grain-size distributions, and 3) geotechnical engineering judgment.

Bedrock materials consisted of claystone, siltstone, and sandstone of the Denver Formation. In general, weathering and fracturing of the bedrock decreased with depth therefore, generally the hydraulic conductivity decreased with depth.

GEI performed a parametric study using the seepage analyses for each representative cross section to evaluate the change in estimated seepage into the reservoir for various depths of penetration of a soil-bentonite cutoff trench into the underlying bedrock.

The results from the parametric study were used in a mass-balance spreadsheet to develop soil-bentonite cutoff trench depth designs for target factors of safety of 1.0, 1.4, 1.6, 1.8, 1.9, and 2.3 against the SEO Design Standard. The results of the parametric seepage analyses were discussed in a meeting between GEI and Denver Water. Based on a qualitative evaluation of risk and cost for the various factors of safety, it appeared that a FOS of 1.5 would provide an appropriate balance between economy and safety. The group concluded that to increase the FOS beyond 1.5 against the SEO Design Standard would require a significant increase in penetration depth for a resulting small increase in the FOS. The Design Standard FOS of 1.5 provides a FOS of 4.5 against the Performance Standard.

For the selected target FOS of 1.5 against the SEO Design Standard, the estimated depth of soil-bentonite cutoff trench penetration into bedrock, computed leakage rate, depth of alluvium to top of bedrock, section length, and total computed section leakage rate for each section analyzed are presented in Table 1. The total length of the soil-bentonite cutoff trench is about 14,800 feet. The soil-bentonite cutoff trench would need to extend between about 4 and 10 feet into bedrock to achieve the
selected seepage design FOS of about 1.5. The weighted average penetration of the soil-bentonite cutoff trench into bedrock would be about 5.7 feet.

**TABLE I**

SOIL-BENTONITE CUTOFF TRENCH DESIGN FOR TARGET
FOS OF 1.5 FOR SEEPAGE

<table>
<thead>
<tr>
<th>Section</th>
<th>Approximate Stations (ft)</th>
<th>Alluvium Depth (ft)</th>
<th>Analysis Cutoff Trench Depth into Bedrock (ft)</th>
<th>Design Cutoff Trench Depth into Bedrock (ft)</th>
<th>Section Length (ft)</th>
<th>Computed Leakage Unit (cfs/sf)</th>
<th>Total (cfs)</th>
<th>Total Cutoff Trench Depth (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>91+00 to 105+00; 118+00 to 129+50</td>
<td>55</td>
<td>4</td>
<td>5</td>
<td>2550</td>
<td>1.06E-05</td>
<td>2.70E-02</td>
<td>60</td>
</tr>
<tr>
<td>2</td>
<td>87+00 to 91+00; 105+00 to 118+00</td>
<td>55</td>
<td>10</td>
<td>10</td>
<td>1700</td>
<td>1.21E-05</td>
<td>2.05E-02</td>
<td>65</td>
</tr>
<tr>
<td>3</td>
<td>5+00 to 10+00; 17+00 to 25+50; 65+50 to 74+00; 82+00 to 87+00</td>
<td>35</td>
<td>4</td>
<td>5</td>
<td>2700</td>
<td>3.04E-06</td>
<td>8.20E-03</td>
<td>40</td>
</tr>
<tr>
<td>4</td>
<td>10+00 to 17+00; 25+50 to 42+50; 49+50 to 65+50; 74+00 to 82+00; 147+00 to 148+00</td>
<td>35</td>
<td>6</td>
<td>6</td>
<td>4900</td>
<td>2.72E-05</td>
<td>1.33E-01</td>
<td>41</td>
</tr>
<tr>
<td>5</td>
<td>0+00 to 5+00; 42+50 to 45+50</td>
<td>35</td>
<td>4</td>
<td>4</td>
<td>1200</td>
<td>2.31E-05</td>
<td>2.77E-02</td>
<td>39</td>
</tr>
<tr>
<td>6</td>
<td>129+50 to 147+00</td>
<td>15</td>
<td>4</td>
<td>4</td>
<td>1750</td>
<td>3.86E-06</td>
<td>6.79E-03</td>
<td>19</td>
</tr>
<tr>
<td><strong>TOTALS</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>14800</strong></td>
<td><strong>2.23E-01</strong> CFS (100.2 gpm)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notes:
1. Alluvium depth is measured from final grade.
2. Total cutoff trench depth from final grade to bottom of cutoff trench.
3. Total leakage includes estimated leakage through soil-bentonite cutoff trench and foundation.

**Construction**

As with the design schedule, the construction schedule was accelerated to have the project completed prior to the start of the 120th Avenue construction. Bidding occurred July 2003 with Envirocon, Missoula, MT, being selected for the construction. Construction of the working platform and staging areas began in early September 2003. Challenges facing the construction team included:

- Accelerated schedule
- Changing topography
- Placement of fill below water
- Narrow working conditions for cutoff trench excavators
- Removal of concrete fill

To accommodate the accelerated schedule, Envirocon’s plan was to start construction of the working platform at the southeast corner of the Hazeltine pit and the northwest
corner of the Brinkmann-Woodward pit and progress clockwise around the collective perimeter of the gravel pits. Once the about 2,000 feet of working platform was constructed from the starting points (headings) the soil-bentonite cutoff trench construction would begin.

The topography of the Road Runners Rest II gravel pit had changed considerably between design and the start of construction due to the ongoing mining operations. This resulted in additional quantities of stabilization fill and areas where the alignment of the cutoff trench was constructed in stabilization fill.

Construction of the stabilization fill consisted of placing sand and gravel below the water surface until the level of the stabilization fill was about 2 to 3 feet above the water surface where compaction equipment could safely work on the fill. The fill was then moisture conditioned and compacted according to the construction specifications. The sand and gravel was borrowed from on-site sources. Figures 4 and 5 show the stabilization fill area prior to construction and placement of stabilization fill along the north side of the Road Runners Rest II gravel pit, respectively.

![Figure 4 – Stabilization fill area, pre-construction.](image)
Figure 5 – Placement of stabilization fill.

During construction Envirocon requested that the stabilization fill above 3 feet above the water surface be a clayey fill instead of the clean sand and gravel to reduce haul distances and cycle times. This request was granted with the conditions the reservoir be operated so the clayey fill would not be below the water surface. There was concern that if the clayey fill became saturated a slope failure could occur.

The working platform was to be a minimum of 55 feet wide (15 outside and 40 inside of the centerline of the cutoff trench) to provide adequate room to excavate the cutoff trench and mix the backfill. In some areas the working platform was narrower than 55 feet. In these areas a mixing trench was excavated to mix the backfill before placement into the excavation as shown on Figure 6.
Figure 6 – Excavating, backfilling, and backfill mixing trench.

During construction an area where concrete had been placed during mining was encountered near the northeast corner of the Road Runners Rest II gravel pit. The concrete fill was about 450 feet long, 50 to 100 feet-wide, and between 1 and 7 feet thick, as shown on Figure 7.
A trench was excavated through the concrete until native soils were encountered and the trench was then backfilled with fine-grained soils. The backfilled soil were moisture conditioned and compacted according to the construction specifications. Before the trench was backfilled, the centerline of the excavation was surveyed to assure the cutoff trench would be constructed through excavated trench through the concrete.

**Soil-Bentonite Cutoff Trench Construction**

Before construction of the cutoff trench, Envirocon developed and performed a laboratory testing program to estimate the proportions of overburden soil, bedrock, dry bentonite, and bentonite slurry that should be field-mixed to produce soil-bentonite backfill that met the minimum hydraulic conductivity specification of $1 \times 10^{-7}$ centimeters per second (cm/s). The soil-bentonite backfill mix design, which is generally representative of field-mixed soil-bentonite backfill used to construct the cutoff trench, is as follows:

- 85 percent overburden soil (by volume, widely graded sand and gravel)
- 15 percent fines, either naturally occurring or borrow soils (by volume, silt and clay)
- 2 percent powdered dry bentonite (by weight)
- Bentonite slurry as required to produce a thoroughly mixed, relatively homogeneous backfill mixture, with a slump between 4 and 6 inches (bentonite slurry consisting of water and 0.5 to 1.0 percent dry bentonite, by weight)

Construction of the soil-bentonite cutoff trench began in early October at the southeast corner of the Hazeltine gravel pit with a Komatsu 750 excavator with a maximum excavation depth of 55 feet. Initially a lead-in trench with an approximate 1H:1V bottom slope was excavated. The lead-in trench served as a ramp to convey field mixed soil-bentonite backfill from the working platform to the bottom of the cutoff trench. Overburden soils were then excavated down to the top of bedrock. A field engineer/geologist from GEI would then determine the top of bedrock from cuttings brought to the surface in the excavator bucket. The depth to the top of bedrock was measured from the edge of the excavation with a weighted tape measure. The depth of the excavation into bedrock was then determined based on the quality and type of bedrock cuttings from the trench. The 750 excavated between about Stations 0+00 and 85+10.

Near the end of October a second excavator (Komatsu 1100, maximum excavation depth of 80 feet) began construction near the northwest corner of the Brinkmann-Woodward gravel pit. Construction activities for the 1100 were similar to the 750. Figure 8 shows the excavation of the cutoff trench with the 1100, note the bentonite bags spaced to be added to the backfill. The 1100 excavated between about Stations 85+10 and 132+90.
Figure 8 - Cutoff trench excavation with Komatsu 1100.

In early December a third excavator (CAT 365, maximum excavation depth of 30 feet) began construction near the southeast corner of the Hazeltine gravel pit. Construction activities for the 365 were similar to the 750. The 365 excavated between about Stations 132+90 and 148+80.

In the areas where the different headings met, the cutoff trenches were either overlapped in the same (confirmed by excavation of backfill) excavation or the excavations were crossed with a minimum of 10 feet at the total depth of the cutoff trench of distance beyond the intersection.

Average production rates, in square feet, of soil-bentonite cutoff wall excavated were estimated for each excavator (i.e., CAT 365, Komatsu 750, and Komatsu 1100). Daily production was estimated by dividing the total quantity of cutoff wall excavation (in square feet) by the number of days required to perform the excavation, as summarized in Table 2.

<table>
<thead>
<tr>
<th>Heading</th>
<th>Based on Days Worked</th>
<th>Days Worked Plus Days Not Worked Due to Mechanical Breakdowns</th>
<th>Days Worked Plus Days Not Worked Due to Mechanical Breakdowns Plus Days Not Worked Due to Incorrect Equipment</th>
<th>Total Excavated Quantity (sf)</th>
</tr>
</thead>
<tbody>
<tr>
<td>365</td>
<td>3.674</td>
<td>N/A</td>
<td>N/A</td>
<td>29,395</td>
</tr>
<tr>
<td>750</td>
<td>3.207</td>
<td>2,784</td>
<td>2,695</td>
<td>253,353</td>
</tr>
<tr>
<td>1100</td>
<td>4.092</td>
<td>3,363</td>
<td>3,031</td>
<td>245,525</td>
</tr>
</tbody>
</table>

Locations where bedrock excavation exceeded the excavation refusal clause, (unable to excavate 1-foot depth over 20-foot long segment for 1 hour) refusal was allowed. These areas were noted during construction and analyses were performed concurrently during construction to determine if the shallower bedrock key would adversely impact the factor of safety for the allowable infiltration into the reservoir. By modifying the seepage analyses from design with the as-built conditions it was determined the shallower key depths would not have a significant impact on the factor of safety because, in general, the bedrock where refusal was encountered was better quality bedrock than assumed during design.

Field and laboratory testing of the freshly mixed bentonite slurry and soil-bentonite backfill occurred throughout construction by both Envirocon and GEI. In general, all tests performed met or exceeded the criteria in the construction specifications.
The results of the laboratory permeability and the percent fines from the gradation tests on soil-bentonite backfill are plotted on Figure 8. The quantity of fines in the backfill does not appear to have an effect on the conductivity of the backfill.

![Permeability vs Percent Fines](image)

**Figure 8 – Permeability vs Percent Fines of Soil-Bentonite Backfill**

After completion of the cutoff trench the site was restored with an access road along the interior of the reservoir. A curing cap was constructed over the cutoff trench to accommodate for drying and desiccation of the cutoff trench and to accommodate for settlement of the backfill.

Design and construction of the project was completed on schedule and on budget.