INNOVATIVE SEEPAGE AND SPILLWAY REMEDIAL DESIGNS OF A PUDDLE CLAY CORE DAM

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ABSTRACT

A risk-based approach was used to develop innovative designs related to embankment and abutment seepage control, and spillway repairs for the high-altitude Continental Dam, located in Colorado, USA. The dam was completed in 1928 and is 94.5 m (310 ft) long and 28 m (92 ft) high that stores 28.2 MCM (22,825 AF) of irrigation water. The zoned embankment has a puddle clay core with sand shells abutted against landside areas. The embankment is founded on native soils approximately 9.1 m (30 ft) of glacial drift (sand with boulders) overlying tuff bedrock. The spillway consists of a 42.7 m (140-ft) long, side channel spillway with a chute that discharges into a natural sands and gravels basin. This paper discusses the risk-based approach used to select the preferred alternative, and then the design and construction of the preferred alternative. The embankment improvements included the placement of a two-stage filter blanket on the downstream embankment face and abutment slopes, toe drain system for seepage collection, and a downstream stability buttress. The spillway improvements included construction of a chute and stilling basin along the right abutment anchored with soil nails and rock bolts, with foundation anchors installed to the underlying embankment along with a new stilling basin. A risk-based design approach should be used for all project sizes to help mitigate design, construction, and safety related risks.

1. PROJECT BACKGROUND

Continental Reservoir, in Hinsdale County, Colorado, USA, is a 28.2 MCM (22,825 AF) reservoir and is impounded by an embankment dam along its northeast side. The dam and reservoir are owned and operated by Santa Maia Reservoir Company (SMRC). The dam is located near the town of Lake City, Colorado, USA. The Colorado State Engineers Office (SEO) classifies the dam as a large, high-hazard structure due to the potential loss of life downstream of the dam during a potential failure.

The dam embankment has a crest elevation of approximately 3136 m (10290 ft) and is a zoned embankment consisting of a puddle clay core and silty, poorly graded sand shells, approximately 94.5 m (310 ft) long and 28 m (92 ft) high as shown in Figure 1. The upstream slope of the main dam varies from 2.5H:1V to 4H:1V, and the downstream slope is approximately 2H:1V. The embankment foundation consists of approximately 9.1 m (30 ft) of glacial drift with a sand and boulder matrix overlying tuff bedrock.

The existing spillway consisted of a 42.7 m (140-ft) long, side channel spillway with a lined discharge chute, and dissipation basin. Initially designed in 1911, the dam was redesigned and constructed between May 1925 and December 1928.

The objective of the Continental Dam Project (Project) was to gain approval from the SEO to remove the 6.7 m (22-ft) reservoir restriction that had been in place since 1994, due to the perceived inadequate spillway capacity, spillway concrete deterioration, and embankment face seepage, so that SMRC can provide reliable irrigation water to shareholders. This was accomplished by rehabilitating and making critical repairs to Continental Dam, which constituted structurally improving the spillway, and controlling and monitoring seepage from the embankment and left dam abutment slide area. Through a flood hydrology analysis it was determined that the spillway could safely convey the probable maximum flood event (Inflow Design Flood) with about one meter of freeboard above what was required by the OSE.

Figure 1 : Continental Dam, Colorado, USA, showing the left abutment slide area that directly contributed to mid-height, downstream dam face, seepage which was a failure mode concern.

The goals of the Project were to mitigate current water management inefficiencies, reduce high maintenance, prevent continued deterioration, and avoid the potential failure of this delivery system. The Project accomplish multiple consumptive and non-consumptive purposes, greatly improving SMRC's ability to (1) meet the agricultural needs of irrigators in 28,328 ha (70,000 ac) of the San Luis Valley, (2) establishing significant improvements in the efficient management of Colorado's Rio Grande Compact water, and (3) supplying storage for Sub-districts in the basin to meet their river depletion requirements.

A risk-based management approach was used to develop alternatives and to identify design and construction risks for the alternatives, and also to identify, and assess risks, and potential risk events related to the design and construction activities. The general approach followed included 1) prioritizing the most significant or critical risks through a risk register, 2) employ risk-based decision making to determine mitigations actions to prioritize risks, 3) determine what was required related to field investigations and engineering analyses to lower the prioritized risks for the project, and 4) monitor the risk environment during the design and construction to be proactive to reduce commercial, environmental, and safety risks.

The highest commercial related risk was related to the unknown embankment and foundation materials. The commercial risks included schedule delays, construction performance, and potential change orders during design and construction. Since the original construction of the project the phreatic surface within the embankment had been elevated indicated by several seepage locations about mid-height of the downstream dam face, when the reservoir elevation was at the spillway crest elevation. Three field investigation programs were performed since 1987 to investigate the potential path of the seepage and what could be done to control the seepage. AECOM performed a limited field investigation program to fill in the data gaps of the previous investigations and to confirm or refute that the puddle clay core was still effective reducing the phreatic surface and to investigate if seepage was being conveyed through the left dam abutment slide area. A reservoir rim seepage location was identified within the glacial drift formation during the investigation. It was concluded that water was transmitted into the slide area and around the dam embankment from the reservoir rim and contributing to the embankment seepage. Preliminary analysis also indicated that the steady state stability did not meet OSE standards so a stability berm would be required.

The spillway alternatives ranged from complete replacement of the spillway to rehabilitating the existing spillway in place. Based on the jointly developed selection criteria (i.e. environmental, social, and technical) it was decided that rehabilitating the spillway in place was acceptable and would provide SMRC a structure that would safely pass the required IDF at the lowest cost. Several alternatives were reviewed to control the seepage from the embankment that included grouting the left abutment, grouting select areas of the dam foundation, constructing an internal embankment cut off wall, and constructing an internal seepage collection system along the downstream dam face. It was determined through the risk-based approach that it would have not been cost effective to grout the left abutment and foundation due to the uncertainty that the grouting programs would reduce the seepage to an acceptable level. The embankment cut off wall was evaluated but it was determined to be too costly and a downstream drain system and stability berm would still be required. The internal seepage collection system was selected as the preferred alternative based on technical merit and cost. The following sections present the details of the Project.

2. SEEPAGE AND EMBANKMENT STABILITY IMPROVEMENTS

A field investigation program showed that seepage was transmitted from the reservoir through the left abutment land slide area surfacing at about mid-height of the downstream dam face. AECOM used a limited investigation program to identify that the seepage was entering along a left reservoir rim glacial drift geologic formation appropriately elevation 3127 m (10,260 ft). The local geology of Continental Dam consists of surficial Quaternary-aged deposits underlain by Tertiary volcanic rocks. The Quaternary-aged deposits are glacial drift which allow potential seepage paths through the formation. The Tertiary volcanic rocks consist of welded and non-welded gray, red, brown, and white tuff.

Several seepage analyses were performed, using SEEP/W, which included several calibration analyses to develop a baseline understanding of the phreatic surface within the embankment. The models were calibrated against the known phreatic surface within the embankment based on piezometer data. Figures 2 and 3 present the results of the seepage analysis that was used to size the filter system and used for the stability analysis shown in Figure 4.

The filter blanket consisted of a two-stage filter consisting of ASTM 33 sand (filter sand) and No. 89 gravel (drain gravel) as shown in Figure 5. The filter sand and drain gravel placed against the re-graded 2H:1V slope was 91.4 cm (3 ft) (horizontal distance) thick which was imported materials. The buttress fill consisted of common fill produced from excavated materials from the spillway chute and stilling basin. It was placed to widen the existing crest by 4.6 m (15 ft) at elevation 3136 m (10290 ft) with a 10 m (33-ft) wide bench at elevation 3129 m (10265 ft). Drain gravel was placed closest to the rock fill in the excavated trench followed by a 1.5 m (5-ft) wide (horizontal distance) filter sand layer. Figure 6 shows the placement of the filter sand, gravel, and common fill.

A toe drain pipe was placed within the drain gravel above the outlet works conduit for seepage collection. Forty-five cm (18-in) diameter HDPE slotted pipe was installed within the drain gravel to convey the collected seepage water to a metering manhole located left of the existing outlet works headwall. Figure 7 shows the toe drain being installed.

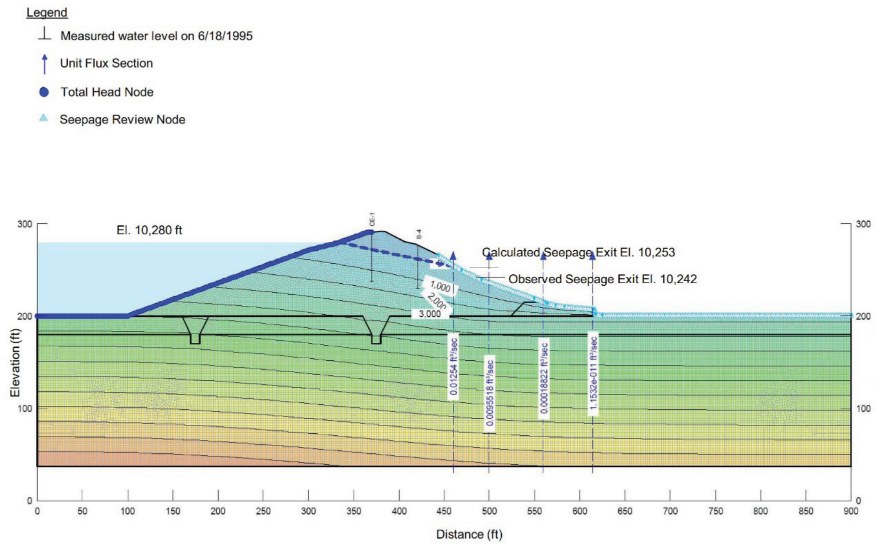

Figure 2 : The calibration model results assuming the puddle clay core was not effective lowering the phreatic surface. The model results indicated that the phreatic surface exit location was appropriately at the observed elevation.

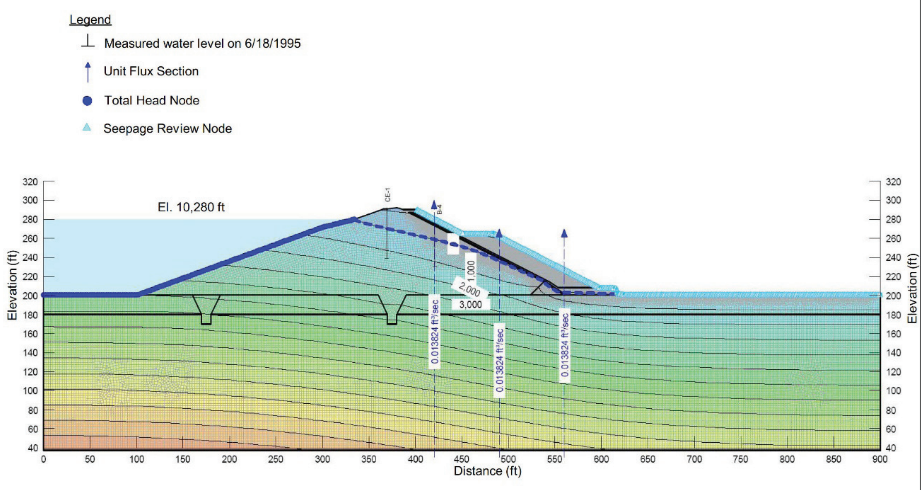

Figure 3 : The model presents the design section of the embankment which included the filter system extending up to the dam crest and the stability berm extending up about 2/3rds of the dam face.

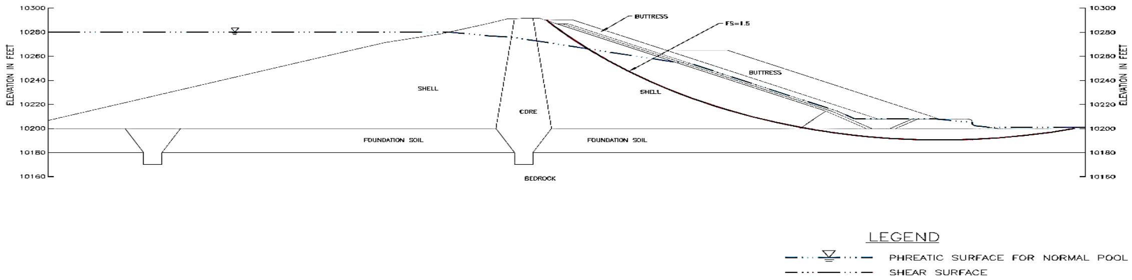

Figure 4 : Stability results from UTEXAS4 and the Spencer's method of slices indicated that the design was suitable meeting the required factor of safety of 1.5 for the steady state conditions. The post-earthquake stability analysis was also performed which exceeded the required factor of safety of 1.2.

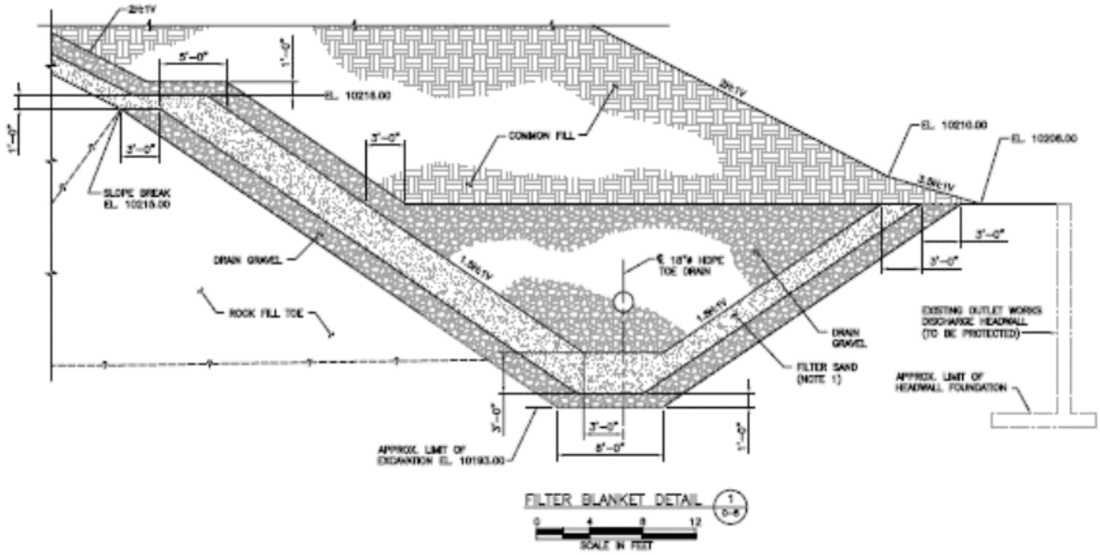

Figure 5 - Filter blanket and toe drain detail. The filter blanket was wrapped along the left groin area to control seepage from the left abutment landslide area.

Figure 6 - Filter sand, gravel, and common fill placement for the filter system and stability berm.

Figure 7 : Toe drain installation which included a 45 cm (18-in) diameter HDPE pipe.

3. SPILLWAY IMPROVEMENTS

The existing spillway was rehabilitated by constructing a new reinforced concrete spillway inside the existing spillway chute walls utilizing the existing walls as forms. The major features of the new spillway included 1) Spillway Underdrain, 2) Spillway Chute Walls and Slab, 3) Stilling Basin Walls and Slab, and 4) Foundation Anchors. The existing spillway was experiencing freeze/thaw concrete deterioration as shown in Figure 8.

Figure 8 : Typical concrete freeze/thaw deterioration within the spillway discharge chute.

The spillway crest consisted of a 42.7 m (140-ft) long overflow into the side channel spillway located along the right abutment contact as shown in Figure 1. Discharge rating curves were developed for the side channel and for the spillway chute to determine which feature would control the spillway discharge for given reservoir levels. The spillway chute walls contain the inflow design flood (IDF) with a minimum of 6.7 cm (2.65 ft) freeboard.

The spillway modifications included the rehabilitation of the spillway chute and installation of a USBR Type II stilling basin along the right abutment. The existing concrete spillway chute was demolished near the toe of the embankment, and a new rectangular spillway chute was installed, with a new floor slab and chute walls being constructed on the interior of the remaining portion of the existing chute. A drainage system was installed beneath the spillway chute. This system consisted of a 20 cm (8-in) HDPE underdrain pipe embedded in drain gravel with a layer of filter sand on the outside of the gravel as shown in Figures 9 and 10.

Figure 9 : Demolition of the spillway invert for installation of the underdrain system within the side channel spillway – side channel control section located to the left in the photo.

Figure 10 : Spillway chute underdrain system during construction.

The spillway chute walls were anchored to the adjacent ground with soil nail anchors and rock bolts, and foundation anchors were installed to anchor the chute floor to the underlying embankment. Figures 11 and 12 show the anchor system being installed along with the forming of the chute walls. Figure 13 shows the completed spillway chute.

Figure 11 : Chute wall anchors being installed.

Figure 12 : Forming right chute wall using the existing wall as a form which helped reduce demolishing costs - the existing wall was characterized as soil for structural analysis.

Figure 13 : Completed spillway chute walls looking downstream into the unfinished stilling basin.

The calculations indicated that a Type II stilling basin with a length of 21 meters (70 feet) is appropriate for the 100-year storm event outflow of approximately 25.7 m^3/s (907 cfs). The trajectory of the stilling basin discharge is away from the toe of the dam and historic performance indicates minimal erosion has occurred downstream of the existing stilling basin. The erosion of the downstream river channel was considered acceptable for floods larger than the 100-year storm event. Figures 14 shows the stilling basin and embankment stability berm under construction. Figure 15 shows the completed project looking up stream.

Figure 14 : Stilling basin to the left and the embankment stability berm under construction.

Figure 15 : View looking upstream at the completed spillway and the stability berm.

4. CONCLUSIONS

The risk-based approach help define the commercial, environmental, and safety risks for the Project. The identified risks were mitigated by adding select construction contingency for groundwater mitigation and potential inclement weather delays due to the high elevation of the project. Through the risk-based approach the project was schedule for two construction seasons due to potential weather construction delay claims by a contractor. The phases included constructing the side channel spillway during the first construction season, and then constructing the stilling basin and embankment improvements during the second construction season. The decision was made to first address the spillway structural condition due to the concern if a flood were to occur the spillway could fail and cause a potential failure of the embankment. The embankment seepage risk was mitigated by lowering the reservoir below the identified reservoir rim seepage location. It was estimated that the approach reduced the overall commercial risk for the Project through the identification potential risks related to the following :

1. Unknown stilling basin and embankment foundations causing schedule delays and change orders, and
2. Higher than anticipated groundwater conditions causing schedule delays and change orders.

Several of the risks were mitigated by adding line item contingencies within the unit price construction contract.

The use of a risk-based management approach should be an industry standard approach for all size projects to protect against commercial, environmental, and safety risks. The process also mitigates potential legal, client dissatisfaction, and regulatory delay risks.