

3. Design, Construction History and Performance

3.1 Design and Construction History

The top of Proffit Mountain was leveled and the excavated rock was used to construct the dike that forms the upper reservoir. The bedrock and thus the rockfill is predominantly a rhyolite porphyry. Little information is available concerning the as-built gradation of materials used in the construction. As described in available engineering reports, the overburden was stripped for the upstream-most 70 feet, as shown in Figure 2-1, and placed downstream to form the bed of the perimeter road. All weathered material was to be stripped from this area to sound rock. Overburden varied from a few feet to as much as 65-feet thick. Clay seams were also removed by excavating during construction. Excavated rock was end-dumped from trucks and sluiced with 30-psi water, to form the ring dike. A filter zone and several layers of compacted rock were placed over questionable areas where piping into the foundation might be possible. Outside of the 70-foot stripped zone, the weathered rock was left in-place. Low areas in the natural topography were also filled with compacted rock. It was reported in the 7th Part 12D report that excavated fines were used to level the reservoir floor.

The upstream slope is 1.3:1 (horizontal: vertical) and the downstream slope is at the natural angle of repose of the material, approximately 1.3:1. The pneumatically placed upstream concrete face slab has a design thickness of 10 inches, and is reinforced with No. 7 bars at 12 inches both ways. In actual placement, the slab thickness averaged nearly 18 inches due to the unevenness of the rockfill. The upstream concrete face had joints (with copper waterstops) located at the junctures with the parapet wall, the foundation cutoff-slab and with adjacent face panels. The face slab was placed in panels, 60 feet wide at their widest dimension. Expansion joints between the slabs to accommodate movement, caused by settlement of the rockfill, used ¾-in asphaltic expansion joint material and U-shaped copper water stops.

A reinforced concrete plinth was provided at the toe of the concrete face. Where the natural rock surface was substantially higher than the reservoir floor, the rock was excavated on a near vertical slope and the plinth was at the top of the excavated rock. In these areas, the rock cut between the reservoir floor and the plinth was sealed with a 4-inch layer of wire mesh-reinforced shotcrete. The entire reservoir bottom was sealed with two-2-inch layers of hot-mix asphalt concrete placed over leveled and compacted quarry muck. Around the edge of the asphaltic concrete, a single line grout curtain was constructed to limit seepage under the dam.

The ring dike forming the Upper Reservoir was closed near panel 50, which is also an area of reportedly finer materials. The dike is topped with a 12-foot layer of horizontally compacted rock placed in 4-foot lifts and compacted with a vibratory roller. The parapet wall was cast-in-place on top of this top layer. Based on observation, it appears the crushed rock varies from 1000 lb stone to predominately less than 20 lb stone. The stone is predominately angular. The outer shell of the dike contains clean rock fill material with more sandy and pebble sized materials in the closure section. Settlement of the rockfill varied between 1 and 2 ft. with the lowest area at Panel 72, where the top of the parapet wall was 1596.99 ft as determined by an AmerenUE survey dated November 6, 2004.

3.2 Panel Comments on Design

The design and construction of the CFRD for the Taum Sauk Upper Reservoir Dam followed the pattern of older CFRD's constructed in California such as Strawberry Dam and Salt Springs Dams. These dams were dumped rockfill CFRD's with slopes ranging from 1.3:1 to 1.4:1. Each of these dams have parapet walls for reflecting waves at normal maximum water storage level; but the maximum water storage levels are always about 1 to 2 ft below the crest of the rockfill. But water levels could possibly encroach on the parapet walls in times of floods. The design decision made for Taum Sauk Upper Reservoir Dam to routinely store water 6 to 8 ft high on a 10 ft high parapet wall during daily operations made the Taum Sauk dumped rockfill CFRD "Unprecedented" as compared to the previous CFRD's, as summarized by Cooke, 1988 (Figure 3-1).

It is noted from Figure 3-1 that nearly 100% of the CFRD's prior to 1963 were dumped and many had cracked face slabs and high leakage. Because of this behavior there were no CFRD's built between 1940 and 1950. As shown on Figure 3-1 Taum Sauk was the last newly constructed dumped rockfill CFRD in the USA; it is also shown in Figure 3-1 that Cabin Creek CFRD was designed at about the same time, but was designed as a compacted rockfill CFRD. Cabin Creek was compacted in 2 ft thick lifts to a height of 70 m (230 ft.) and was an Upper Reservoir Dam for a pumped storage project in Colorado. The maximum section of Cabin Creek Dam is shown in Figure 3-2 which shows an upstream slope of 1.3:1 and a downstream compacted slope of 1.75:1. It is especially important to note that the maximum operating level is 6 ft below the rockfill crest of the dam, and 9 ft below the top of a 3 ft high parapet wall on the crest of the dam. The differences in the Taum Sauk and Cabin Creek CFRD designs represent differences in risk tolerances for different engineering firms and individual consultants during the same time frame taking into account the state of the art for CFRD design in the middle 1960's. It should also be noted that Cabin Creek Dam was overtopped by pumping, but did not fail.

3.3 Embankment Performance

As described above in Section 3.1, the embankment is a rockfill structure with a parapet wall and has experienced considerable deformation and settlement beginning with the first filling of the reservoir. For example, there were settlements in excess of one foot within the first two years of operation (1963 – 1965). These settlements continued, although at a lower rate, until 1976, when they leveled somewhat, to as much as 1.6 feet of settlement along the NW sections of the embankment. See Figure 3-3 for the movements of settlement points 1 through 23. The plan location of these points are shown on Figure 3-4. The last survey data shown from January 2004 indicates that the settlements have not increased since 1987, and any changes over the past 20 years appear to be within the accuracy of the surveys.

In late 1963, only several months after first filling, major repairs were necessary along the interior of the NW section of embankment, upstream of Panels 91 and 92. These repairs consisted of excavation, grouting, developing a concrete cut-off, and joint repairs. Throughout the following several years additional repairs were continued to control leakage and distress to the embankment and foundation as well as the face slabs and parapet walls. As can be seen on the plot of crest settlement, Figure 3-3, as well as variations in the top of the parapet wall shown on Figure 3-5, "Crest Survey Data", surveyed along the dam and parapet wall after the breach, there were significant elevation differences along the crest of the parapet wall. There were areas such as those at parapet Panel No. 72 with elevations as low as El 1597 and several other panel areas ranging in elevations from EL 1597 to 1598. Also shown on Figure 3-5 are elevations of the top of the parapet wall for Panels 69 through 75, as surveyed by AmerenUE on November 6, 2004.

The leakage from the Upper Reservoir has been a continuing problem and concern beginning in September 1963. As an example, during that time a sudden increase in seepage to 103 cfs was experienced and emergency measures were taken to repair with concrete plugging in two holes in the floor at panels 91 and 92. Three days later, another episode of increased leakage caused another shut-down and repair. The repair consisted of excavating a 230 ft. long by 4 ft. wide trench, excavated to "rock" and backfilled with concrete at Panels 90 to 93 and 95. A number of repairs were made throughout subsequent years focusing more on leakage through the horizontal and vertical joints in the concrete facing. Particular emphasis was on the joints between the concrete facing and bedrock, the joint at the toe of the parapet section, and the joint between the concrete facing and plinth. Higher rates of leakage (40 to 100 cfs) began in 1999 following an extended outage. It is shown in Figure 3-6 that the leakage increased significantly after 1999 as the plant was used more extensively after replacing the runner and increasing the Plant efficiency. Thus, the project suffered from several episodes of seepage concerns throughout its history. The effects of all of the leakage on the embankment cannot be exactly

determined; however, it surely had an effect on increasing the settlement up to 1987 and potential movement of materials. A geomembrane liner was subsequently installed in 2004, which significantly reduced the leakage to about 5 cfs for the 12 months prior to the breach. Figure 3-6 shows the history of leakage and the periods of repairs. A chronology of events dating from submittal of the geomembrane liner design in January 2002 through the breach event of December 14, 2005 is given in Appendix B, which is taken from the FERC Report of Findings on the Taum Sauk Upper Dam Failure.

Thus, the Upper Reservoir Embankment has had a long history of settlement and high underseepage. Its performance as an effective water barrier was difficult to gage, since it has, in-fact, performed over the past 42 years. Although there were many periods of concern and needed repair to keep the water within the reservoir, the embankment and parapet wall did function as the containment for the Upper Reservoir. The rockfill embankment, as discussed in Section 3.1, was a steep dumped rockfill and the storage of water on the high parapet wall was unprecedented. There was most likely no margin for additional loading or overtopping, as was the case with the breach on December 14th. The holes which developed on the upstream side of Panels 90-95 in the 1963-1964 time frame suggested that the plinth was not extended to rock in that area, as should have been done, for a normal CFRD constructed in the middle 1960's. As discussed in Section 6, Figures 6-5, 6-6, and 6-7 indicate that the actual plinth was not extended down to rock. Early project correspondence by J.B. Cooke, M.W. Fler, Raymond Weldy and an unknown Union Electric employee are given in Appendix C, which refer to early behavior of the Upper Reservoir and the possible resistance to erosion in the event of overpour over the parapet wall.

Horizontal misalignment of joints in the parapet wall in the area of the breach were noted in the 1967 Safety Report and in the 2003 Safety Report as given below.

In the August 19, 1967 Report on Safety, Mr. Cooke cites offsets in March 1966 on the order of 1/4 inch with several joints near Panel 88 at 1 to 1.5 inches.

In the 2003 Part 12D Report, the consultant states horizontal movement included rotation and translation of the wall joints. The report states:

“The maximum horizontal movement observed was at joint 89/90 and 106/107, with about 4-5 inches of translation and rotational movement. --- panel 90 having moved downstream relative to panel 89. The copper waterstop was visible in the joint. This magnitude of movement is likely sufficient to tear the waterstop, but probably does not affect the wall stability.”