A DAM INCIDENT AT SUGAR CREEK L44

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Abstract

Sugar Creek Site L 44 and many other sites in Caddo and surrounding counties received 8 to 10 inches of rainfall within 3 to 4 hours on Sunday, August 19, 2007. Rainfall amounts were reported to exceed the 100-year rainfall for 24, 12, and 6-hour storms and the 500 year rainfall for a 3-hour storm. The rainfall led to very high auxiliary spillway (ASW) flow, erosion of the inside training dike, erosion of the ASW down to the underlying bedrock, erosion of the downstream toe of the dam near the ASW outlet, and instability of the embankment. The Emergency Action Plan was activated in response to the incident and demonstrated the effectiveness of the NRCS, State Conservation Commission, Conservation District, and local authorities. The embankment instability resulted in subsequent slope failure, which ultimately proceeded through a portion of the crest of the dam by the evening of August 19, 2007. A road embankment and culvert with a history of plugging is located immediately downstream. An Engineering Report was completed by an investigation team consisting of two engineers and a geologist from the Natural Resources Conservation Service.

This paper will present the findings of the Engineering Report which includes a brief chronological description of the project planning, design, construction, and site history; the effect of the downstream channel and road embankment on the tail water; tail water effects on the downstream slope of the dam, ASW, and ASW training dikes; and the effect of the bedrock geology in the ASW had on the erosion of the training dike and the downstream slope of the dam.

Project Description

Sugar Creek L44 Dam is an earthfill embankment dam providing flood control located in Caddo County, Oklahoma. The drainage area above the dam is 1,709 acres. The maximum fill height is 64 feet and the length of the embankment is 550 feet. An as-built plan view of the dam is shown in Figure 1. The auxiliary spillway had a width of 40 feet and is located in the left abutment.

The Sugar Creek Site L44 Dam was built by the Soil Conservation Service (now the Natural Resources Conservation Service) as a low hazard dam in 1971. The dam was reclassified to a high hazard, dam due to downstream development but had not been rehabilitated to meet high hazard design criteria.

The as-built drawings indicate the core of the dam was to be constructed of silty clay materials and both the upstream and downstream zones of sand or silty sand. The vegetated auxiliary spillway consisted of silty sand surface soils underlain by sandstone.

A rural road is located approximately 300 feet downstream. A 78-inch culvert passed under the roadway prior to construction of the dam.

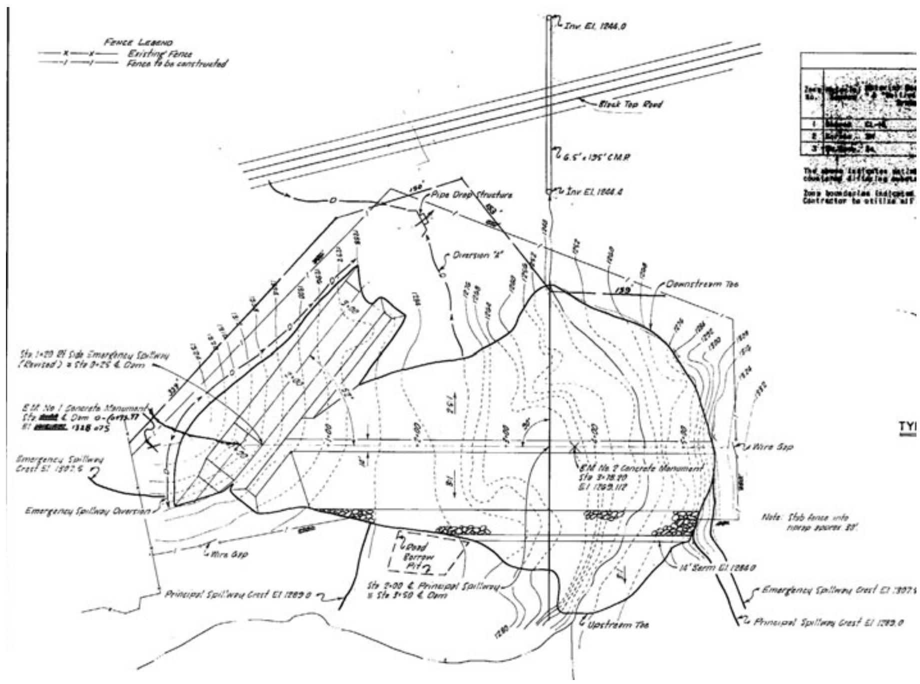

Figure 1 – Plan of Embankment and Spillway

Sequence of Incident Events

The following sequence of events was complied from project records and interviews from local personnel:

September 1967 – 32,000 cubic yards (CY) estimated for stream channel common excavation in schedule of quantities contained in the planning documentation.

December 1969 – Detailed Geology investigation for project completed, included an investigation for downstream release channel approximately 1,700 feet in length with 10 foot bottom and 4:1 side slopes.

May 1970 - Earthwork computation worksheet for stream channel excavation indicates 5,505 CY above road and 26,495 CY from an undetermined area for a total of 32,000 CY.

July 1970 - Filter Material Worksheet calculations indicates 1,510 CY channel excavation below road on back of worksheet.

July 1970 – Sheet 4 of 16 (Contract Drawings) indicates revision of auxiliary spillway location. Auxiliary spillway right side shifted 95 feet toward embankment on centerline of dam stationing and outlet channel rotated toward dam from 61.5 degrees to 52 degrees. The exit channel slope was also increased from 7.5 degrees to 9.75 degrees.

August - September 1970 – Contract Drawings, Specifications, Bid Schedule, Engineers Estimate are finalized.

October 1970 – It was decided the site could be contracted if the "release flow channel is planned to be constructed to and through the County road bridge."

May 1971 – Construction records indicate a bull dozer was working downstream of the road.

May 1971 - Dam construction was completed and accepted.

1972 – Sediment completely covered the principal spillway outlet

April1973 - Easement granted, NW ¼ section 1 (700 feet long and 100 feet wide), for channel improvement downstream of road from DOI-BIA to South Caddo SWCD. Approximately 1,000 feet of additional easement still remained according to the Geology Investigation and was not obtained.

1972 -1979 – County installed a 24-inch diameter culvert with inlet approximately 15-feet above the principal spillway outlet. The actual date of installation is unknown.

March 1979 - A Phase 1 Inspection Report was completed by the Corps of Engineers. The report noted the dam was classified as a high hazard dam, could pass 30% of the PMP, seepage was observed from the left side of the dam, the culvert through the road was completely covered with sediment.

May 1987 - The downstream road washed out. No damage to the dam or ASW was reported.

1988 - County Commissioner repaired the road and placed a riser and 18 inch pipe through the road. The original 78-inch culvert through the road was never found.

August 18, 2007 – Local Fishermen indicated the reservoir water surface was near the principal spillway (PS) crest.

August 18, 2007, 10:00 pm Light rain began

August 19, 2007, 2:00 am – Intense rain had ended and many local roads were washed out.

August 19, 2007, early am – Caddo Rural Electric Company personnel report a water depth over the road of approximately 3 feet.

August 19, 2007, 8:00 am – Nearby resident observed the roadway was beginning to fail and ASW was flowing.

August 19, 2007, 8:15 am – Resident observed the entire road fill had failed. He did not observe any failure in the dam from his view on the right abutment. The breached roadway embankment is shown in Figure 2.

Figure 2 Downstream Road Breach

August 19, 2007, 11:00 am – District personnel observed ½ to 1 foot of water flow through the ASW. The erosion in the embankment was 4-foot wide near the downstream crest.

August 20, 2007, 8:00 am – The ASW flow had ended and the erosion in the dam was up to the top of the dam and widened, as shown in Figures 3 and 4.

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Figure 3 Crest of Dam

Figure 4 Eroded Auxiliary Spillway taken from Road

August 20, 2007, pm – ASW was notched to lower the pool.

August 23, 2007, am – Two large 3,000 gallons per minute (GPM) pumps placed and begin pumping to lower the pool.

August 28, 2007 – Restrictor plate was removed from the riser.

August 29-31, 2007 – Notch was excavated through the embankment to reduce storage volume to prevent flooding of downstream homes in case of a dam breach

Evaluation

Summary of Possible Cause

Possible causes of ASW erosion and downstream toe erosion:

1. Rainfall and associated auxiliary spillway flow exceeded the allowable stress of the vegetated highly erodible earth ASW.

2. Tail-water created by the county road reduced principal spillway capacity and thereby lengthened the ASW flow time.

3. ASW flow eroded the right training dike which eventually allowed flow towards the downstream toe of the dam

4. The combination of tailwater and the auxiliary spillway flow created circular flow regimes between the right training dike and dam leading to erosion of both.

5. The combination of tail-water and the auxiliary spillway flow created overtopping and erosion of the right training dike and underlying soil.

6. Once the soil in the ASW eroded, the ASW flow was directed towards the downstream toe of the dam due to the slope of the underlying bedrock. The presence of the 10 to 15 foot near vertical rock ledge allowed increased erosion into the downstream toe of the dam.

Probable Cause

A SITES analysis to model the storm event was completed. A rainfall of 8.5 inches was assumed to occur over 3.5 hours. A five point distribution was assumed for the rainfall event. Other rainfall distributions such as straight line distribution and one with 99 percent of the rain within 2 hour were also modeled. The elevation of the pool and peak flow through the ASW was similar for each of these assumed rainfall distributions. The peak pool elevation appeared to match the observed high water marks. Peak flow through the ASW was estimated to be 740 cubic feet per second (CFS) or 18.5 CFS/Ft. The velocity in the ASW channel was estimated to be 10.0 feet per second. Erosion of the vegetated ASW surface is expected at these flow velocities.

Flow from the county road drainage area, Principal Spillway (PSW) and ASW filled the area between the dam and the road before the ASW flow peaked creating tail-water to an elevation of approximately 1295-feet. During this timeframe the ASW outlet channel flow was impeded by high tail-water. The road downstream from the embankment acted as a secondary dam because neither the original outlet conduit nor the culvert outlets installed by the county functioned. It should be noted that each subsequent outlet installation submerged the principal outlet pipe from approximately 15 feet to 21.9 feet, respectively. It appears the original 78 inch conduit was completely submerged in alluvial sediment at an unknown time after construction was completed. Probing attempts in 1988 with a backhoe and in 2007 with an iron bar to locate this conduit were unsuccessful. The second road culvert (24-inch) was destroyed when the road breached in 1987. The road culvert (18-inch) installed in October, 1987 maintained a tail-water elevation of 1271.4-feet. The inlet structure culvert did not function well, if at all, during the 2007 storm and was found plugged with debris at the inlet. The sponsors acknowledged trouble keeping debris from plugging any drop structure they had installed. These conditions allowed drainage from the roadway along with PS and ASW flow to impound water between the road and the dam until the road overtopped and subsequently breached.

Geology Technical Note 4 (Rev. 2), January 1987, states on page 13:
"*2. Unfavorable rock structure in the floor of the spillway (Figures 4, 5, 6, 7, and 8) can concentrate flow and erode the retaining dike. If the dike is breached, the uncontrolled flow can damage and possibly breach the abutment and embankment (Figures 10 and 11)*."

Figure 5 of this paper shows figures 7 and 10 from the technical note. The early failure of the retaining dike led to uncontrolled flow damaging the abutment and nearly breaching the embankment. This scenario exists for the bedrock under the as-built ASW, as shown in Figure 6.

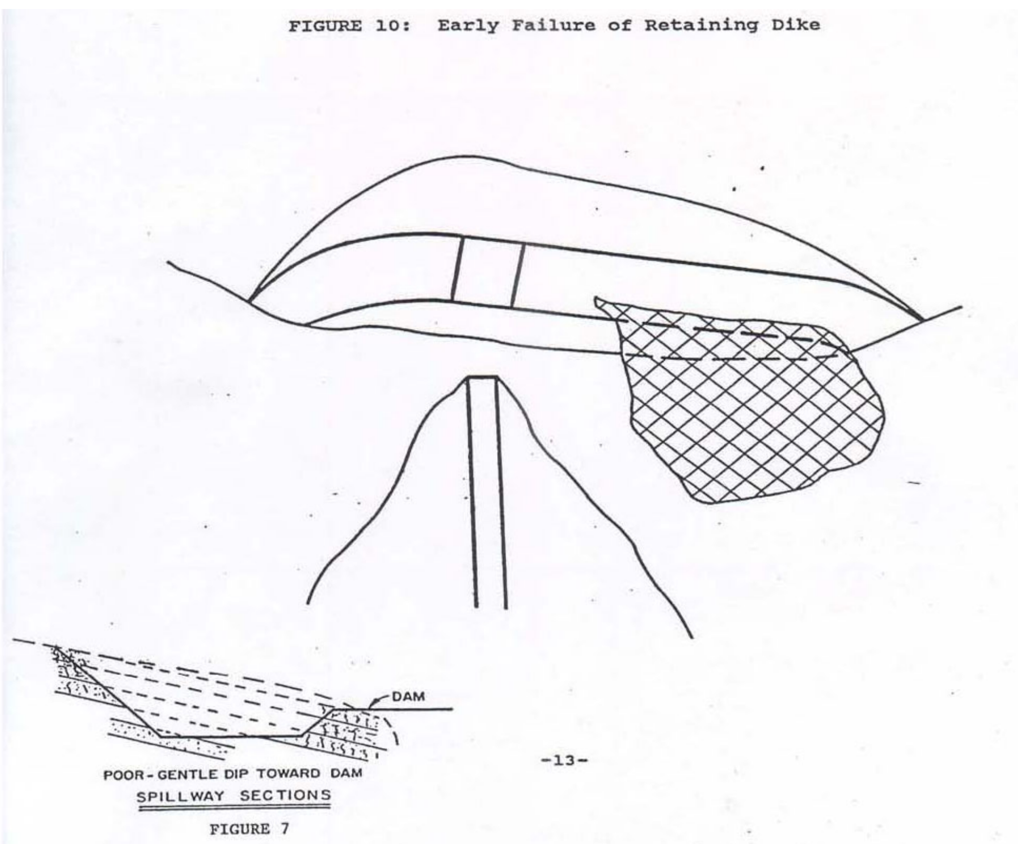

Figure 5 Geology Technical Note Figures

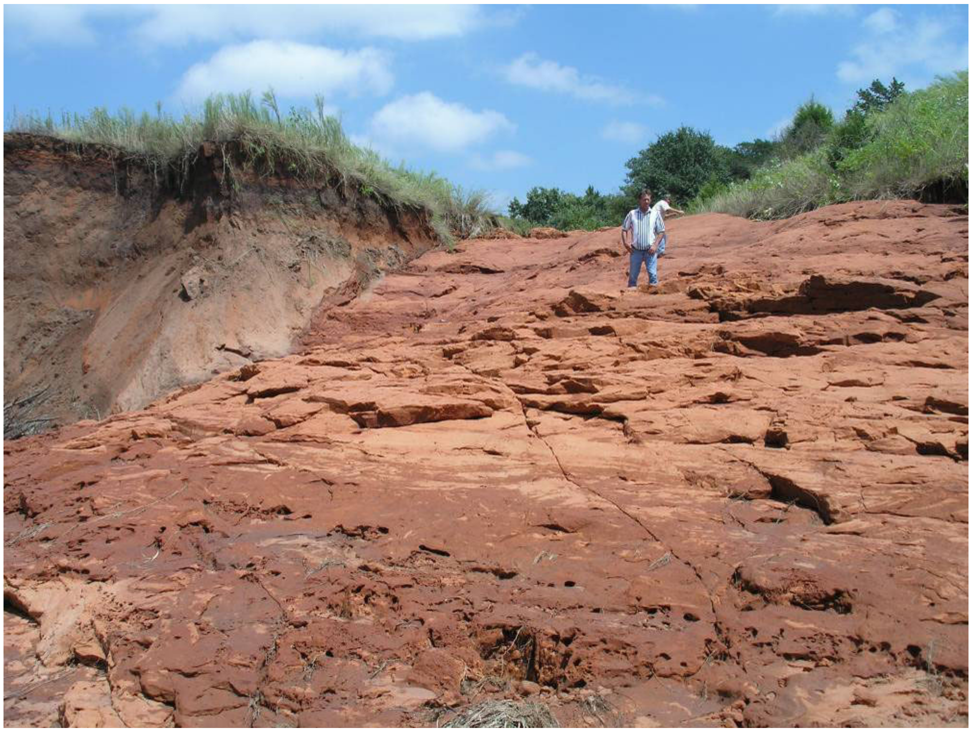

Figure 6 Exposed bedrock in ASW sloping toward dam

Relocation of the ASW from the original layout along with increasing the slope of the exit channel to 9.75 degrees occurred prior to construction. Unfortunately, and unknowingly, the ASW relocation placed the training dike directly over a near vertical outcrop of the sandstone that the spillway flow had eroded down to and exposed. This outcrop provided a 10+ foot near vertical outfall that added to the hydraulic energy when the training dike eroded, as shown in Figure 7 and 8. A plan view of the ASW superimposed on the exposed rock in the ASW is illustrated in Figure 9. This exposed rock surface was surveyed immediately after the 2007 event. This sketch displays the highest tail-water of 1295, which indicates that the lower 27± feet of the top of the dike were submerged to that elevation.

Figure 7 Near vertical outfall of over 10 feet at groin of dam and abutment

Figure 8 Near vertical outfall running entire length of ASW outlet channel
Note: Uncontrolled pumped discharge attempting to flow towards the dam

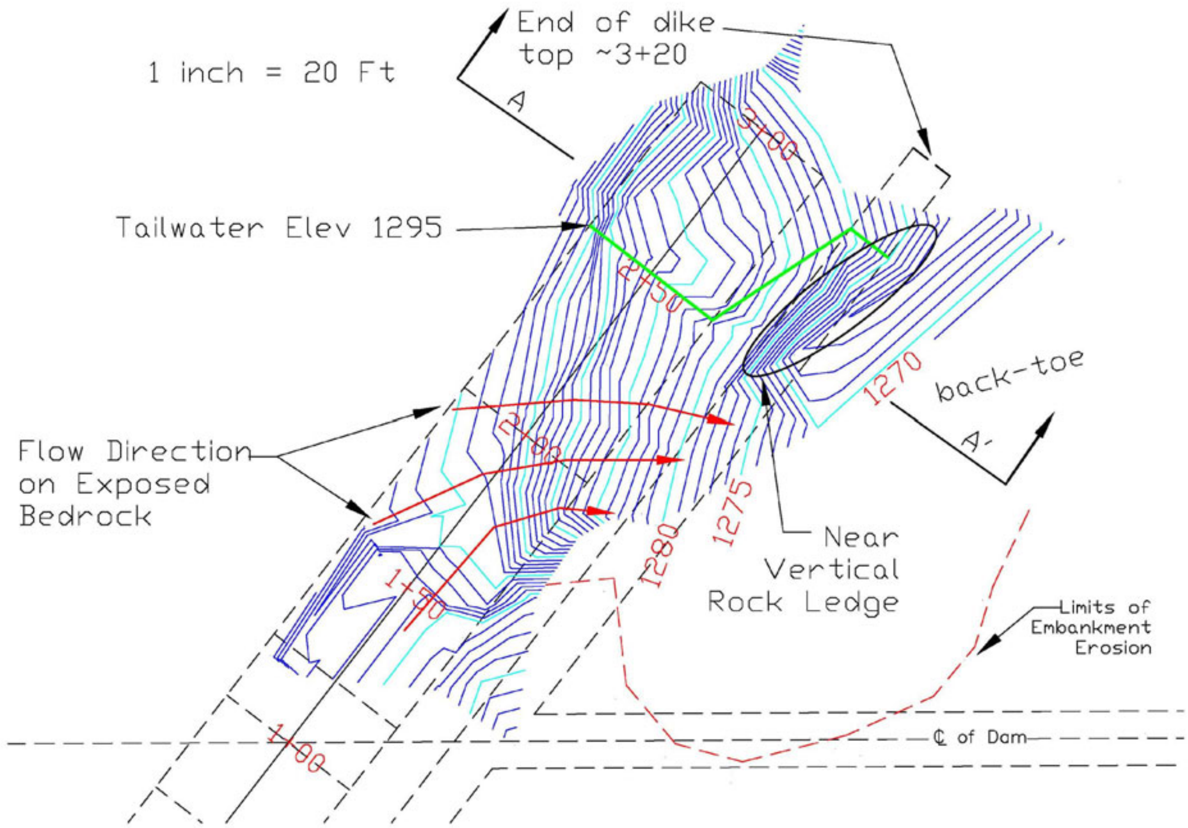

Figure 9 Plan View superimposed on exposed rock contours

Analysis of tailwater elevations indicate the water level was overtopping the end of the inside training dike prior to the road being overtopped. This high tailwater could create eddies across and over the top of the training dike from spillway flow, thereby initiating erosion along the top of the dike. As the tailwater rose to the ultimate elevation of 1295, the erosion across the top of the dike not only moved upstream along the dike top, but also potentially increased in magnitude.

Subsequent breaching of the road and rapid drop in tailwater level allowed continuous and more than likely rapid, down-cutting through the dike. The adverse geology, described above would have accelerated the headcut advance up the groin of the structure to the crest of the dam.

Once the top of the dike eroded through, the process continued down cutting through the dike, especially when the road breached and the tailwater began to subside. The near vertical outfall of 10+ feet added additional energy to the erosive forces, and the head cut advanced up the groin of the structure close to the position outlined in Attachment 10a. Attachment 10a also illustrates the flow direction of the ASW. It should be noted that the flow concentrated directly toward the inside edge and into the near vertical outfall. The headcut advance allowed the dike to be eroded away and the abutment groin headcut to advanced to approximately Station 1+80, as shown in Figure 10 (photo looking upstream on ASW).

Figure 10 Headcut advance into abutment and embankment groin

Conclusions

1. Rainfall and associated runoff led to significant ASW flow. The peak flow was near but less than the flow expected from the Freeboard Hydrograph for a class "a" dam.

2. The decision to proceed with construction without the easement for the necessary downstream channel improvements followed by the inability to complete the planned downstream improvements led plugging of the road culverts and to an increase in tail-water against the downstream slope of the dam and into the lower reaches of the ASW. The tail-water elevation was also increased by the subsequent installations of much smaller culverts by the County. The tail-water forced ASW flow to overtop and erode the end of the training dike. Once the dike and adjacent soils eroded a head-cut progressed along a 10-foot near vertical rock ledge immediately below and adjacent to the dike and then up the groin of the dam and ASW. Saturation of the lower downstream slope of the dam due to high tailwater increased the erodibility and decreased the stability of the soils on the downstream slope.

3. The dike may have been eroded by a combination of 1) overtopping flow and erosion and 2) lateral erosion due to high velocity flow contained in the ASW directed at the dike by the slope of the exposed bedrock. The highly erosive nature of the soils combined with the flow event allowed the severe erosion.

4. Although the high tailwater is believed to have contributed to and increased the ASW and embankment erosion, significant ASW erosion would have occurred without the effects of the tailwater.

5. Failure of the road embankment resulted in a surge of water that flooded one house downstream with18 inches of water and was close to flooding 2 other homes.

Recommendations

- Since the hazard classification of the dam has increased from low hazard to high hazard, rehabilitation/repair of the dam is recommended. An alternative to upgrading the dam to high hazard criteria is to remove the downstream hazard and repair the dam as a low hazard dam.

- The available alternatives for rehabilitation to high hazard include: decommissioning, widening the existing auxiliary spillway in the left abutment with some structural considerations, construction of a second auxiliary spillway in the right abutment, constructing a roller compacted concrete (RCC) spillway over the top of the dam, or construction of a new dam along the road alignment downstream.

- If vegetated spillways for either the rehabilitation as a low hazard or high hazard dam will not meet the TR-60 design criteria, the use of articulated concrete blocks (ACBs) or other structural measures could be considered to protect the ASW against erosion or breach.

- If a vegetated or earth/rock spillway is incorporated as part of the rehabilitation, excavation of the ASW in the right abutment rock should be considered.

- Coordinate repair of the downstream roadway and channel improvements to insure adequate drainage capacity downstream of the dam is constructed and maintained.

- When associated improvements to downstream channels or other resources are required for a project to function as designed, continued efforts to accomplish the improvements is recommended.

References

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5. United States Department of Agriculture, Natural Resources Conservation Service. 2007. Engineering Report, Sugar Creek Watershed, Flood Retarding Dam No. L 44, Fort Worth, Texas.