MEMORANDUM

To: Kent Jones
State Engineer

From: David Marble DKM
Assistant State Engineer / Dam Safety

Date: November 15, 2012

Re: Santa Clara Dam Failure / UT00443

The Santa Clara flood control dam failed on September 11, 2012 during a storm event that filled the reservoir to the spillway. This dam only impounds water during storm events where runoff into the basin exceeds the capacity of the 10 inch outlet conduit. The outlet conduit discharges downstream into a storm sewer system. Very little design or construction information about this structure is available. According to the dam safety database, the dam is 93 years old having been built in 1919. The owner of the dam is Santa Clara City.

On the day of the failure the Santa Clara City Public Services Director visited the dam to observe its performance during a rain storm. At the time of his initial visit he noted that the reservoir was filling and was at an elevation of 9 to 10 feet below the spillway. He also indicated that during the previous week the reservoir had filled to near the spillway, but had essentially drained prior to this event. He left to observe flood conditions in other parts of the city and returned to Santa Clara dam about ½ hour later. At that time, he observed that the reservoir was full and spilling. He also noted a leak near the center of the dam about 4 feet below the crest. This leak was described as a "jet of water" similar to that from a garden hose. Photograph 2 shows a similar "jet of water" at a second, somewhat lower, leak. Concerned with the safety of the dam, the Emergency Action Plan was initiated and city police were contacted to evacuate the downstream inundation area.

The breach of the dam was well documented by eyewitnesses and through photography, both still and video. According to the time recorded on the digital pictures, early photographs of the initial leak were taken just before 12:30 pm. Photographs shows 3 initial water leaks on the downstream face of the dam. The dominant leak that controlled the breach was located near the maximum section of the dam. Its elevation is 4 or 5 feet below the crest (Photograph 2). A small leak, possibly related to the first and labeled "Third Leak" on photograph 2, can be seen in video footage (it is difficult to see in still photographs) adjacent to and at the same elevation as the dominant leak. Another distinct leak can be observed a couple of feet lower and is labeled "Second Leak" on photograph 2. Seepage from the dominant leak quickly eroded downward through the downstream slope and body of the dam. In just over an hour the entire dam was breached and most of the reservoir evacuated from the basin.

The Mayor of Santa Clara estimates that the failure resulted in private property damage as high as $5 million and that damage to public infrastructure could be as high as $2.5 million. News reports indicate that 66 homes and 18 businesses, along with roads, sidewalks and other infrastructure were flooded. That there were no reports of fatalities or other injuries is attributed to Santa Clara City's prompt implementation of the Emergency Action Plan (EAP) and evacuation of the downstream population at risk.

Important observations made during the failure include:

- Within about ½ hour, the reservoir rose 9 to 10 feet to reach the spillway AND leaks developed near the center of dam 4 to 5 feet below the crest.
- The observed leaks were concentrated in discrete locations.
- The reservoir was spilling at an undocumented depth but less than 1 foot (Photograph 1). The dam clearly did not overtop.
- Erosion of the embankment cut down quickly from the observed concentrated leaks located below the dam crest (Photographs 3 and 4).
- The crest of the dam collapsed into the downward cutting erosion.
- Witnesses described rodents swimming away from their burrows in the upper portion of the dam as the reservoir water flooded their tunnels.
- Late in the breach process water was observed flowing from a concentrated hole, which appears to be a rodent tunnel, in the middle of the embankment into the breach (Photograph 7).

Important observations made following the failure include:

- Photography (video and still) taken during the breach confirms witness accounts of leaks in discrete locations at elevations 4 to 8 feet below the crest (Photograph 2).
- The dam cross section was homogeneous. Laboratory testing of the embankment soils have not been conducted but appear to be silty sand (SM) to sandy silt (ML), typical of soils in the area.
- Gullies were formed in the upstream face of the dam from backflow out of rodent holes as the reservoir dropped during the breach (Photograph 8).
- The central and downstream portions of the embankment the day following the breach appeared to be dry while only the upstream shell was wet (Photograph 6).
- Dam freeboard was approximately 3 feet.
- Following the failure, the nearly vertical failure slopes of the breach were cutback for public safety purposes. During excavation some evidence of what was described as a possible construction seam was observed 5 to 6 feet below the dam crest.
- While significant property damage occurred, no injuries were reported (Photograph 5).
- While infrequent, there are reports that the reservoir has previously filled to near the spillway, but there are no reports of previous flow through the spillway. It is possible that the reservoir reached a slightly higher elevation than has previously occurred.

Evaluation of Observations

Final determination of the cause of any dam failure, including this one, is difficult since evidence at the failure location is washed away. Detailed still and video photography, along with eyewitness reports, are of tremendous value in evaluating the cause of this failure. The following observations are considered to be key indicators of the cause of failure.

- The location of the dominant leak that controlled the failure was at the maximum section near the center of the dam.
- Its elevation was 4 to 5 feet below the crest, nearly the same elevation as the water in the reservoir.

- Concentrated leaks developed very rapidly after the reservoir elevation reached the spillway.
- The location of concentrated leaks varied in elevation below the dam crest.
- Witnesses observed water pouring into existing rodent holes in the embankment.
- Post failure observation of the "dry" embankment implies that a phreatic or free water surface through the embankment, associated with traditional backward erosion piping, did not develop.
- The embankment was constructed of highly erodible soils without internal zoning and drainage features that provide defensive design provisions against failure.

All of these observations support the premise that the dam failed from internal embankment erosion resulting from open cracks or conduits that allowed nearly instantaneous seepage through the dam and down the downstream face of the embankment. During previous storms that nearly filled the reservoir, the dam performed adequately. The defects that resulted in the failure were either newly developed or due to the slightly higher elevation of the reservoir during this event which allowed reservoir water access to these defects.

Evaluation of Potential Mechanisms

The possible sources of concentrated leaks are as follows:

- Transverse cracking due to differential settlement.
- Hydraulic fracturing, or cracking, in the embankment caused by hydrostatic water pressure from the rising reservoir.
- Construction related, highly permeable seams that extended through the embankment.
- Rodent burrows that penetrate through or nearly through the embankment.

Cracking from either settlement or hydraulic fracturing is likely to develop soon after construction of a dam and/or initial filling of the reservoir. Cracking from differential settlement is likely to develop near a steep abutment rather than near the center of the dam. Residual cracking 93 years following construction of the dam is unlikely.

Hydraulic fracturing develops at locations where arching or bridging of soils may result in areas of low stress. Typically this phenomenon occurs along rigid penetrations through the embankment, such as an outlet conduit, or near abrupt changes in transverse slope faces such as the valley bottom and a steeply sloping abutment. High pore, or water, pressure that develops within the embankment during fill placement can also contribute along lift lines if proper bonding is not achieved. Again, 93 years after construction with previous incidents of reservoir filling, the possibility of this potential failure mode seems unlikely.

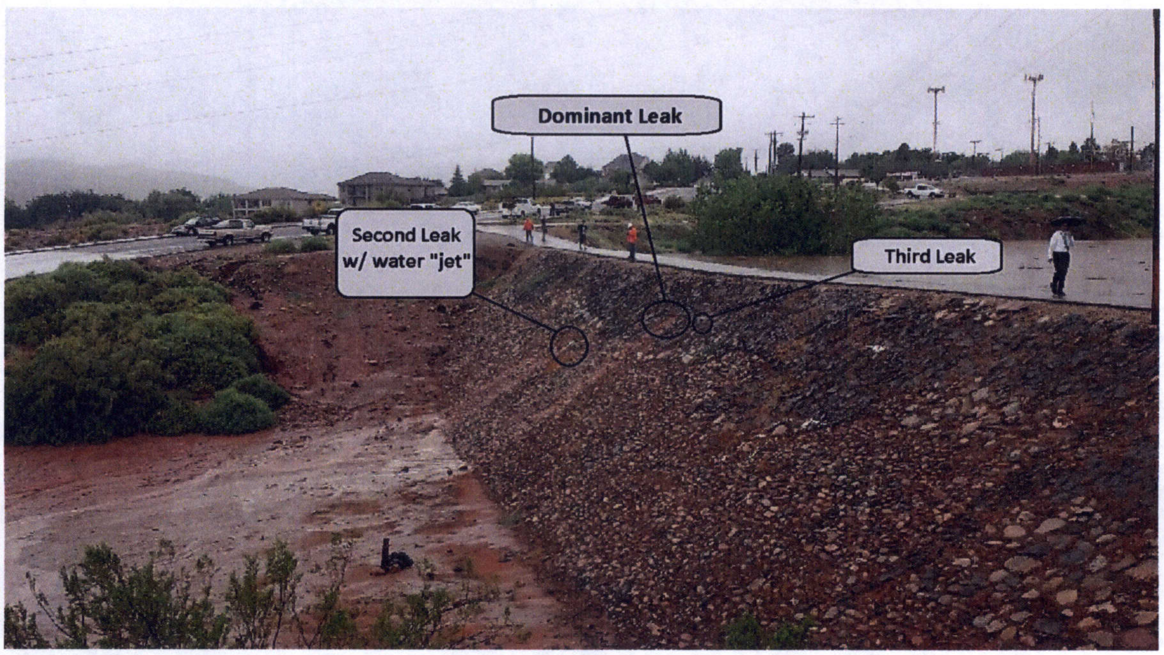
The construction seam reported in the excavation of the failure slope was described as having a slight difference in color and was possibly "crusted" as might be expected from a surface that had extended surface exposure. It was reported that the embankment soil above this seam may have been looser than soil below it and with more prevalent rodent activity. Its gradation was not considered to be abnormally coarse nor did it appear to have high enough permeable to explain the development of rapid leakage as observed. If seepage resulting from such a seam were to develop, it would likely occur along the length and elevation of the seam rather than in concentrated locations with varying elevations. This possibility does not appear to be likely.

Concentrated leakage through rodent burrows is a plausible, even likely, explanation of the failure based on the observations made and evaluation of available data. Dam Safety inspections of the dam have documented the presence of active rodent holes in the embankment near the dam crest. Failures of small dams and levees or canal embankments have been attributed to rodent burrowing. Rodent burrows can be extensive and pervasive (Photograph 9). USU extension services have documented that pocket gopher tunnels can be 5 to 6 feet below the surface and that the total length of tunnel systems can be up to 600 feet. Silty Sand / Sandy Silt embankment soils are highly erodible and have low cohesion making them relatively easy for rodent digging but still capable of supporting tunnels. It is possible that burrowing could have extended through this homogenous embankment or that separate burrows dug into each face may have met or nearly met in the middle. Witness observations of water flowing into rodent holes (and back out of the holes with reservoir drawdown) and rodents swimming away when burrows were swamped provide additional support.

Conclusion

The failure of the Santa Clara Flood Control Dam was by internal embankment erosion through concentrated leaks located near the center of the dam, and within 4 to 8 feet of the dam crest. The embankment was built as a homogeneous structure, without internal zoning or drainage system, and with soils that were highly erodible. Based on available evidence, these leaks most likely developed through rodent burrows and tunnels in the embankment.

Photograph 1 – Spillway at maximum reservoir elevation



Photograph 2 – Concentrated leak through the dam

Photograph 3 – Failure progression

Photograph 4 – Failure complete

Photograph 5 – Downstream flooding

Photograph 6 – Post failure

Photograph 7 – Concentrated flow through hole into breach

Photograph 8 – Post breach, rodent holes with gully from backflow

Photograph 9 – Grouted ground squirrel burrows exposed in landslide levee slope at Robbins, California