

Memorandum

To: Mr. Paul Dunlap, California Department of Water Resources
From: Oroville Dam Spillway Incident Forensic Investigation Team
Date: May 5, 2017
Re: Preliminary Findings Concerning Candidate Physical Factors Potentially Contributing to Damage of the Service and Emergency Spillways at Oroville Dam

According to the Work Plan, the Forensic Investigation Team's (Team's) assignment is to complete a thorough review of available factual information to develop opinions on the chain of conditions and actions that caused the damages to the service spillway¹ and emergency spillway at Oroville Dam, and why opportunities for intervention in the chain of conditions or actions may not have been realized. Evaluations of actions and decisions for the various stages of the project (pre-design, design, construction, and operations and maintenance) will consider the states of practice applicable to those various time periods.

At this time, the Team is still in the information gathering and review stage of its work, and it has not yet reached conclusions. However, the Team recognizes that the California Department of Water Resources (DWR) is in the process of designing and constructing interim and permanent repairs to the service and emergency spillways at Oroville Dam. As requested by DWR, to provide input to the repair efforts, the Team provides the following preliminary lists of candidate physical factors that are being considered as potentially contributing to the damages that occurred at the spillways in February 2017. At this time, the Team does not believe that it is likely that there are singular physical causes of the spillway damages, but rather that the damages were the results of some combination of physical factors from the lists below. However, based on what is known at this time, it would be prudent that the design of repairs consider all of the physical factors listed below.

Separate lists of physical factors are provided for the service spillway and the emergency spillway. The reader is cautioned that additional factors may be identified as the investigation proceeds.

Candidate physical factors potentially contributing to service spillway damage:

1. Thinning of the chute slab above herringbone drains; these locations can promote cracking.
2. Large variations in slab thickness.
3. Limited slab reinforcement consisting of one layer of light reinforcement in the top of the slab.
4. Lack of continuous tension reinforcement across slab joints.
5. Corrosion and failure of reinforcing bars across cracks.

¹ The service spillway has historically been referred to as the flood control outlet (FCO) or flood control outlet spillway.

6. Slab joints with insufficient keys or lack of keys.
7. Slab placement sizes which were too large to control cracking.
8. Lack of waterstops in slab joints.
9. Hydraulic pressures and flows transmitted beneath the slab sections through open cracks and joints.
10. Increase in spillway discharge shortly before slab failure.
11. Plugging or collapse of drains or collector pipes, including potential plugging by tree roots.
12. Flow into the foundation that exceeded the capacity of the drain pipes, including possible flows from areas adjacent to the chute.
13. Lack of redundancy in collector drains.
14. Unfiltered drains; the gravel envelope may not serve as a filter.
15. Herringbone drains crossing joints in the slab.
16. Weathered rock and completely weathered rock that is soil-like material as slab foundation, without appropriate modification of the chute slab design, resulting in potentially erodible material beneath the slab and lack of foundation bond with concrete; the weathered rock and completely weathered rock appears to be associated with geologic features such as shear zones, and the degree of weathering changes relatively rapidly between some areas of the chute slab.
17. Less rigorous foundation preparation, resulting in lack of foundation bond with concrete.
18. Extended drought impacts on foundation materials.
19. Insufficient anchorage, due to limited anchor development in the concrete, short anchor length, inadequate grouting or grout strength, and/or installation in weak foundation material.
20. Relatively high spillway flow velocities in the lower chute for higher spillway discharges.
21. Lack of durability and effectiveness of slab repairs.
22. Spalling and/or delamination of concrete at slab joints.
23. Groundwater pressures; although current evidence suggests this may not have been a significant factor.
24. Cavitation; although preliminary analysis suggests this may not be a significant factor.

Candidate physical factors potentially contributing to emergency spillway damage:

1. Significant depth of erodible rock and soil in orientations that allowed rapid headcutting toward the crest control structure; these materials also appear to be associated with geologic features such as shear zones.
2. Hillside topography that concentrated flows and increased erosive forces, facilitating headcut formation.
3. Insufficient energy dissipation at base of the spillway crest.
4. Absence of erosion protection downstream of the crest structure.

It is important to understand that not all of the factors listed above may eventually be judged to have significantly contributed to the actual damages to the spillways, after all facts and as-constructed conditions are collected and fully evaluated. However, these factors should be considered and addressed in the ongoing new design and construction.