TBD

by Charles Hoes

Spring has just about sprung as I write this where I am. Of course, many might question whether or not that even applies to California? What that means is there's a good chance we are past the worst of the winter storms. If we remain incredibly lucky, California's Oroville Dam might actually hold together long enough for critical repairs to be completed this spring and summer. I don't think people appreciate just how close the spillway failure came to being a massive, unbelievable catastrophe. When the powers that be issued the emergency evacuation order for the surrounding communities, they fully expected the spillway to burst within the hour. They didn't say that it "might" fail within the hour; they said that it "would" fail within the hour. Luckily, they were wrong. It is not clear how large a catastrophe that would have unleashed, but it would have been far larger than 200,000 people running for their lives indicates. That, as they say, would have been just the tip of the iceberg.

A dam failure (although apparently, the dam itself wasn't in danger of failing; rather, it was the top 50 feet or so of the spillway) of this magnitude would have immediately demolished the towns directly downstream. It probably would have also caused the entire Sacramento River, and possibly the San Juaquin River, to breach their levees and spread out across the width of the valley. At the time of the event, the entire river system in California was full to overflowing due to heavy rains and many simultaneous levee failures were already in progress. I live on the western edge of "The Valley" — in what used to be the shallows of the annual lake that was the Sacramento Valley. I expected my house to be flooded only four or five feet deep, based on the behavior of previous floods in my neighborhood. The resulting flooding from the loss of the dam, plus the loss of miles of levees, would have returned the entire valley back to its original untamed state of being a vast, temporary, inland sea.

This raises some interesting considerations from the system safety point of view. For one, are events such as this even within the purview of our profession? After all, wasn't this really an act of nature? I suppose the periodic flooding of the valley could be considered an act of nature, but once nature was "tamed," it seems to me that *we took responsibility for the consequences*. It would have been unimportant if there were no buildings, no facilities and no infrastructure to protect — but we built levees and dams to control the rivers so that we could make use of the area for our purposes.

Assuming these are the kinds of things that system safety should be involved with, it is pretty amazing to observe what actually appears to have happened. Based on my rather hazy recollection from 55 years ago, I recall that this particular dam was controversial from its inception because it is the highest dam in the United States. It is perhaps the largest earthen dam in the world (depending on the definition of "largest"), is built on top of an earthquake fault and is situated so that its failure would destroy much of the Sacramento Valley infrastructure. Supposedly, it is built to withstand the strongest possible earthquake in the area — assuming anyone actually knows what that might be. As the lake filled, the weight of the water and the dam caused a number of local earthquakes, which further ramped up the public's fear of a dam failure. If I recall correctly, one of the solutions to the possible failure of the dam and spillways because of earthquakes was to add an emergency spillway that worked by simply being overtopped — no fancy mechanisms required. Of course, since it was assumed that this event would never happen, the emergency spillway was never verified as capable of actually containing the flow of water that might result. It turns out that it couldn't, and the flow that it was actually exposed to was nowhere near the maximum possible (or credible).

Then came the day the main spillway failed. We all watched in horror as the "pothole" got larger and the destruction became immense, while the lake level continued to rise rapidly with no safe way to control it. I doubt if the cause of the pothole will ever actually be

determined, but it is almost certainly going to involve problems with maintenance and inspection. My personal guess is that it will turn out to be similar to the failure of the Glen Canyon spillway tunnel that was caused by cavitation starting in a small hole in the concrete's surface. It started with a penny-sized hole, but the resulting cavitation eroded a series of downstream, ever-expanding holes until one eventually got large enough to rip the entire bottom half of the spillway tunnel system apart from the inside, spewing massive chunks of concrete and rock. Of course, the lake was full at the time — so full that temporary plywood walls were built on top of the dam to extend it enough to contain the inflow of water. (I recommend the book *The Emerald Mile* by Kevin Fedarko for an exciting description of a river boat ride down the Colorado River as the Grand Canyon was flooded by the failing Glen Canyon dam.)

Once the Oroville spillway started to come apart, officials were in uncharted waters, described hourly in the local — and global — news media. They tried the obvious solution of throttling back the flow in the hopes of limiting the amount of destructive erosion, thinking that the untried and unproven emergency spillway would work (I suspect this included a bit of "cross your fingers and hope for the best" decision making). That approach didn't work because the emergency spillway became the source of the emergency rather than a solution. The only choice was to increase the flow through the main spillway and once again hope for the best. The officials lucked out — the erosion slowed when it finally dug down to bedrock and, thankfully, the rains stopped.

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While this is a lucky situation and we seem to have dodged a nasty bullet, the show might not be over just yet. There remains a record amount of snow in the Sierra Mountains above the Oroville Dam. There are also nine lakes full to the brim because each dam is managed by separate entities and they don't coordinate with each other (at least, not sufficiently to avoid their all becoming full at the same time). If we happen to have a big, warm rain (which is common in California at this time of year), it could rapidly melt the snow — and the water will have no place to be stored. Therefore, all of that water will end up in Oroville Lake, with its badly damaged spillway and out-of-commission emergency spillway. Oroville Lake is currently 50 feet below the emergency spillway. During the storm that led to the problem, the water level of the lake rose over 75 feet *in one afternoon*. This lake is capable of rising 50 feet in a matter of hours; therefore, the emergency could start all over again. By the time you read this, you will know whether that happened.

Part of the problem that led to the overall emergency was that debris built up downstream of the main dam's power plant, requiring that the flow be shut off to protect the turbines. This removed a small, but vital, bit of control by eliminating the capability of discharging 15,000 gallons per minute through the turbines (apparently, they can't release water through the power plant without it going through the turbines). During the past couple of weeks, officials have been frantically digging debris out of the river so they can restart the turbines and get a bit more flow capability when the inevitable snow melt water arrives this spring and summer. To accomplish this work, they shut off the spillway, stopping the flow of water in the river. This has caused massive fish kills because the fish were stranded, and has resulted in the extensive collapse of levees and destruction of orchards along the levees, tearing out farmers' wells and pumps.

While this was an exciting event to enliven the dark days of winter, the presence of dangerous dams is not all that unusual. Most of the dams in California fall into the category of "high hazard" because they are located above population centers. Many are poorly maintained and appear to be primed for creating their own emergencies should conditions line up. Perhaps they are all perfectly safe and have no problems — or perhaps we are living with false confidence.

My question is whether or not this is an example of a "non-traditional" system safety problem that we could, or should, be involved with. There are many parts of this discussion that seem like traditional system safety issues. The concerns range from siting, initial design, on-going inspection and maintenance, communications between involved entities such as various dam operators of upstream dams, and downstream impacts of levee design and maintenance, among others. It seems like a classic system safety problem, with classic system safety failures of many of the elements coming together at the same time. Actually, the problems were always there — it just took a specific set of circumstances to unveil the hazards that had been hidden from view.