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OROVILLE OVERHAUL

To protect the public from catastrophic flood risk, crews race to wrap up emergency spillway repairs at the tallest dam in the U.S. **(P. 16)**

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BEATING THE CLOCK

Engineers and workers at Lake Oroville race to complete critical spillway repairs to mitigate catastrophic flood risk for downstream communities.

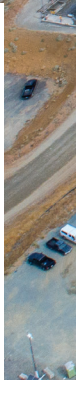
By Scott Blair in Oroville, Calif.

The Lake Oroville spillway's 400-acre construction site is an intense flurry of activity. In one corner, an excavator driver uses an old tire as a squeegee to clean away loose rock and prep a foundation. In the steeply sloping spillway chute, a crane operator flies in a rebar cage to workers who tie it into neighboring chute wall segments. Everywhere, dump trucks buzz around the circuitous roadways while rock crushers and batch plants keep pace with dozens of dozers and excavators. Drones hover in the sky photographing and surveying the site, while inspectors pour over every detail of the finished assets.

Seemingly chaotic but actually highly choreographed and sequenced, the $1.1-billion Lake Oroville Spillways Emergency Recovery Project moves at an ultra-fast-track pace for one important reason: to repair the structures in time to protect cities, farmland and hundreds of thousands of people downstream of Oroville Dam before Northern California's rainy season begins in November. The scale of the task is immense. Once the spillways are complete, crews will have moved over 1 million cu yd of earth, cleaned 239,000 sq yd of foundation bedrock and crushed 2.3 million tons of aggregate—all in just 18 months.

On the Edge of Disaster

Completed in 1968, the 770-ft-tall Oroville dam—tallest in the U.S.—was equipped with a 3,055-ft-long main spillway. It also has an emergency spillway that had never been used. That suddenly changed in February 2017. After weeks of heavy rain filled the reservoir to capacity, dam officials with the California Dept. of Water Resources (DWR) were forced to ramp up water releases from the main spillway. After a large chunk of that spillway's concrete was



BIG FOOTPRINT
After record rainfall in winter/spring 2017, water released from Oroville Dam tore through the main spillway chute and hillside (below). Repairs include a new splash pad apron (upper left of top photo) below the emergency spillway and a more robust concrete main spillway (right). Crews place structural erosion-control concrete (bottom right).

PHOTOS: (TOP AND BOTTOM LEFT) COURTESY DWR; IMAP DATA© 2018 GOOGLE. INEGI; (LOWER RIGHT) BY SCOTT BLAIR/ENR

Redding
Oroville
Reno
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San Jose
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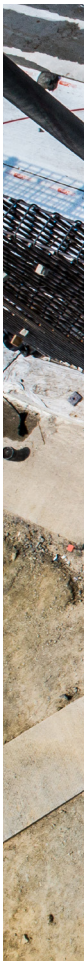


FORM FUNCTION One of twelve lattice cranes flies a pre-assembled rebar cage for a section of spillway chute wall into place (left). Once the cage is tied into place, workers install formwork and ready it for concrete (middle).

gouged out from the heavy flows, water was held back to assess the damage. More heavy rains caused the lake to overtop the emergency spillway—essentially an engineered low spot on the dam similar to the edge of an overflowing bathtub. When the torrent began undercutting the front of the emergency spillway's weir, threatening to send an uncontrolled wall of water downstream, emergency managers sent out an evacuation order for almost 200,000 people living in the City of Oroville and other low-lying communities.

Despite a few warnings over the years from environmental groups and dam safety experts that the emergency spillway could be at risk, the crisis took many residents by surprise. The city's mayor, Linda Dahlmeier, recalls turning her cell phone off during the short flight home from San Diego that day. "By the time I landed in Sacramento, they had called the emergency evacuation," she says. "My daughter lives in that low-lying area with no cellphone service at her house. She only had about 15 minutes to get out, and that was with four of my grandkids. My knees just completely buckled. It was like living in the Twilight Zone."

Leaving a Scar

To prevent overtopping, DWR again released water down the main spillway. While this averted the disastrous erosion of the emergency spillway and surrounding hillside and allowed residents to return home, the releases continued to erode the main spillway, eventually leaving a 1,100-ft-long, 200-ft-deep scar in the spillway and adjacent hillside.

Once the rains abated, DWR was "faced with a major dam safety emergency and an unprecedented challenge to construct new spillways within eight months," says Ted Craddock, the agency's executive manager for the Oroville Emergency Recovery. DWR quickly assembled a team of 100 engineers to draft enough of a design to bid the project. General contractor Kiewit Infrastructure West began spillway work on May 20, 2017.

The main spillway work was divided into two phases because no construction could occur during the winter rainy season from December until May. Phase one, completed November 2017 (ENR 12/11-18, 2017 p. 10), rebuilt two sections of reinforced structural erosion-control concrete in an 870-ft-long upper chute section and a 350-ft-long lower section. Crews also placed some 350,000 cu yd of roller-compacted concrete (RCC) to fill the massive gouge and to create a temporary spillway surface and walls. The relatively undamaged portion of the old spillway just below the gates remained in place for the season.

In May, crews ramped up again to demolish the rest of the old spillway, remove the temporary RCC and complete the main spillway's permanent structure by placing concrete for the new walls and slab in an alternating checkerboard-like sequence.

PHOTOS COURTESY DWR

PHOTO COURTESY DWR

TOP DOWN
Crews work from atop the 20- to 34.5-ft-tall wallforms to place concrete on a spillway chute wall segment. The team will place 126 wall sections this season alone.

"We started the season with 504 concrete placements to perform. Last year we had 312," says Jeff Petersen, Kiewit's project director. In the main chute slab, structural concrete is placed in 30-ft-long, 37-ft-wide and 2.5-ft-thick blocks atop a course of leveling concrete about 5 ft thick on average. Each block, reinforced with two layers of epoxy-coated 1-in.-dia rebar—compared with just one layer of uncoated rebar used for the 1968 spillway—gets anchored to meticulously cleaned foundation rock via 15- to 25-ft-long anchor bolts. The original damaged spillway used fewer bolts that penetrated only 5 ft. More than 7,000 anchors will be used by the end of the project. Drains have also been redesigned to lie further below the slabs compared with the original 1960s design.

Homegrown Solution

Last season, concrete finishing crews found that pulling a screed up a 25% slope by hand was slow, expensive and exhausting. This season, engineers fabricated a homegrown solution, nicknamed "Franken-screed" because it's an assemblage of disparate parts. A carrier beam holds the 37-ft-wide screed, which is then pulled up-slope using portable electric winches mounted on the frame. While similar equipment is commonly used for leveling concrete on flat ground, Franken-screed's modifications for use on the steep grade and its portability via crane make the apparatus one of a kind, Petersen says.

Wall sections run along each side of the 178.5-ft-wide spillway and range from 20 ft to 34.5 ft in height. They vary in width from 2 ft at the top to about 5 ft at the base.

"To accelerate the schedule, we pre-tie the wall cages out on grade beside the spillway and then we fly them in and tie them in place," Petersen says. This allows crews to form the cage while the bottom slab is still curing. "It takes a little extra steel and a template to hold the wall cage up, but the time savings way offsets the cost of doing the extra rebar."

As of Oct. 1, crews had completed all but 51 of the final season's segments, and barring any last minute problems, should complete the main spillway two weeks ahead of schedule, says Tony Meyers, DWR project manager.

A batch plant with an ice maker the size of a small building produces the required 77,000 cu yd of leveling concrete and 82,000 cu yd of structural and erosion-resistant concrete for the job. After running along a wet belt that chills the aggregate by 20° F, the ice drops the mix to around 55° F. To reduce it even further, crews inject 600 inches of liquid nitrogen each day into the mixer trucks to lower the concrete to 40° F before placement, says Kevin Bock, Kiewit plant manager.

Last season, the concrete mixes were "some of the hardest that anyone associated with this project had ever seen," Meyers says. As a result, this season's mix was reconfigured with larger aggregate to have a compressive strength below 12,000 PSI. The mix will help to slow

the curing process and reduce the minor surface cracking that occurred on some of last year's slabs, he adds.

Meanwhile, at the bottom of the spillway, workers perform work akin to dentists by re-capping massive tooth-like dentates that will help to dissipate energy as water flows from the spillway into the Feather River below.

Twelve lattice cranes and two hydro cranes serve the host of activity along the length of the spillway and around the site.

Splash Down

When work on the main spillway paused during last winter's rainy season, the project team focused on repairing and bolstering the emergency spillway. Crews embedded a 1,450-ft-long secant-pile wall into bedrock at depths between 35 ft and 65 ft. The wall will prevent the head-cutting erosion that occurred in February 2017, DWR designers say. Currently, operations are running full tilt to complete a 1,830-ft-long by 750-ft-wide splash pad apron, incorporating more than 700,000 cu yd of RCC. The apron's stair-step pattern will help dissipate the energy of any water released over the emergency spillway.

The RCC's finish also acts as an energy dissipater, says Phil Kelley, RCC superintendent. The RCC is placed in 1-ft increments, and excavators use GPS to stay on the correct grade. Kiewit "fabricated a special plate on another [excavator] to act as a trowel to give us this finish, which is a newer innovation that we were able to come up with," he adds.

At the base of the emergency spillway weir, crews installed 650 steel dowels to support an RCC buttress that will further bolster the structure.

Even though the splash pad doesn't need to be completed before the rainy season starts, the work is running six to eight weeks ahead of schedule and should wrap up around Nov. 1, DWR's Meyers says.

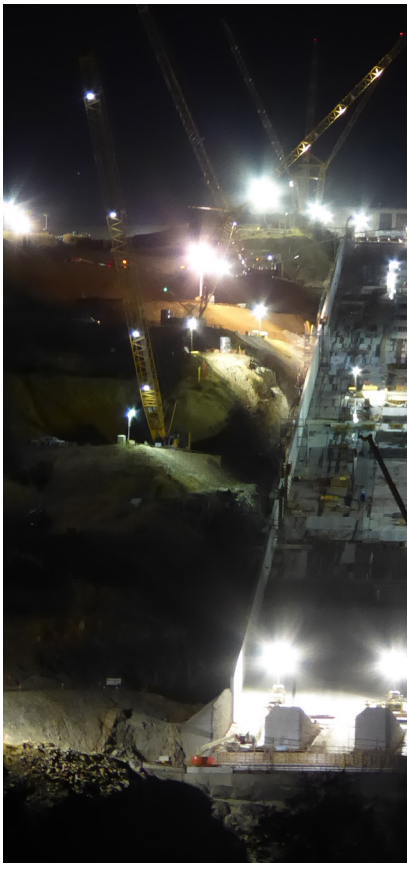
As the project team makes its final push, Kiewit retains more than 700 workers on site working around the clock Monday through Saturday, along with a single shift on Sunday. An additional 275 DWR designers and other employees are still working on the project. Since the spillway incident, more than 1,000 DWR staff have had a hand in design and oversight.

So far, Kiewit has reported two recordable incidents after more than 1.5 million work hours. "There's been roughly 2 million hours between Kiewit and DWR on the job, so it's pretty amazing how few injuries there have been with the amount of contiguous, adjacent and overhead work, [risk of] trips and falls, confined space and the amount of people and resources in the area," Meyers says.

Of the project's overall $1.1-billion cost, Kiewit's contract comprises the majority, at $630 million. The initial emergency response in spring 2017 cost $160 million, and another $310 million has been spent on debris and

GO WITH THE ROLL
Workers lay roller-compacted concrete in layers to create an energy-dissipating stairstep pattern on the emergency spillway splash pad apron.

PHOTO (LEFT) COURTESY DWR; (MIDDLE) BY SCOTT BLAIR/ENR



sediment removal, power line replacement, permitting, DWR staff, technical consultants and other support, says Erin Mellon, DWR's assistant director for the public affairs office. When the spillway's fix originally went out to bid, DWR used $275 million as a "preliminary cost so we could get the contractor on the ground and start mobilizing," Craddock says. "On a typical project like this, you'd have a multiyear design investigative effort [to determine cost]. We had a few weeks," he adds. The initial design was taken to about 30% completion at bid, with remaining design work conducted over the first few months of construction, he adds.

At peak of construction, Kiewit put in place $2.5 million worth of work in a single day on the project, and currently is spending $2.3 million per day.

Work will continue into 2019 on backfill and approximately 1 million cu yd of additional earthwork to restore the slope of the hillside, remove crane pads and other rough grading, says Meyers. The final component, environmental restoration, is just entering the early design phase. Additionally, the road to Lake Oroville's boat ramp will be reconstructed and reopened to the public in summer 2019.

Restoring Public Trust

It's not just the site that's in need of restoration, many observers say. DWR "has a big hill to climb in terms of trust, particularly with the state legislature and the community," says state Sen. Jim Nielsen (R-Red Bluff). "They've got to get better, and the legislature will be exerting greater oversight."

A final independent forensic report issued in January found that while no one cause led to the incident, factors included a "long-term systemic failure" by DWR—as well as regulatory and general industry practices—to recognize and address inherent spillway design and construction weaknesses, poor bedrock quality and deteriorated spillway chute conditions.

In late September, Gov. Jerry Brown (D) signed into law legislation sponsored by Nielsen that sets up a community oversight committee to "ensure the community will be involved with and informed about all things going on at Oroville," says Nielsen.

Since the incident, DWR has escorted hundreds of elected officials and local media on site tours, held numerous community town halls and attended community events to "be a better community partner," Mellon says.

"The lesson of Oroville is: Do not neglect inspection and deferred maintenance," Nielsen says. But lessons learned go well beyond Oroville. The spillway incident "was a really sad wake-up call to the nation that our infrastructure is crumbling," says Dahlmeier. ■

SEE VIDEO ONLINE AT enr.com

PHOTO: (RIGHT) COURTESY KIEWIT

INVENTIVE
On the steeply sloping lower spillway chute (middle), crews struggled to operate screeds by hand. Enter the "Franken-screed" (right), a device that pulls the screed mechanically up the 25% slope.