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ROBOT TIES STEEL ON PENNSYLVANIA BRIDGE

NATURE'S FAULT

Team replacing dam in seismic zone mitigates risk from ancient landslides, torrential rains and naturally occurring asbestos

A bnp media PUBLICATION

MOVING MOUNTAINS

Replacement dam near Calaveras Fault strengthens San Francisco's water-supply system

By Scott Blair

PHOTO COURTESY OF DRAGADOS USA/FLATIRON WEST/SUKUT CONSTRUCTION

Buffeted by torrential El Niño downpours, menaced by naturally occurring asbestos and threatened by a major nearby fault, the team constructing the Calaveras Dam Replacement Project in the mountains east of San Francisco Bay has had more than its share of hurdles to overcome since the project began six years ago.

"This project is all about Mother Nature and what she could do," says Susan Hou, East Bay regional project manager with the San Francisco Public Utilities Commission, the agency responsible for the 220-ft-high, zoned earth-and-rockfill dam, which replaces a similarly sized dam built more than 90 years ago.

Mother Nature's greatest gambit on the job was laid down thousands of years ago: Ancient landslides lurked beneath the soil; despite ample probing by geologists, two remained undiscovered until excavation began.

Delivering a seismically resilient dam in these geologic conditions has turned the originally $416-million, four-year effort into a saga costing $810 million and taking eight years to wrap up. On many projects, such an outcome would cause turmoil and finger-pointing within the team and angry protests from taxpayers. But by using detailed risk-mitigation tracking and proactive partnering sessions, the team has persevered without a single claim.

The need to replace the existing Calaveras Dam, built in 1925 and located in the Sunol Valley southeast of Fremont, stemmed from an earlier attempt to build a hydraulic fill dam in 1911. When that nascent dam was nearly complete, its entire upstream face failed and slid into the reservoir. While engineers at the time tried to clean up the debris as much as possible, "the problem was [that] some of that loose material was left in the foundation" of the 1925 dam, making it susceptible to liquefaction and failure during an earthquake, says Dan Wade, director of the SFPUC's $4.8-billion Water System Improvement Program (WSIP), approved by voters in 2002 to repair and upgrade resiliency on critical portions of San Francisco's regional water system. With the Calaveras fault just 1,500 ft away from the dam and capable of a magnitude-7.25 earthquake, California's Division of Safety of Dams in 2001 deemed the dam seismically unsafe. SFPUC had to lower the reservoir to just 40% of its original 96,850-acre-ft capacity. While most of San Francisco's water comes from the Hetch Hetchy Reservoir 167 miles east of San Francisco, the reduction at Calaveras hamstrung water managers, especially during California's recent severe drought.

Calaveras remains the largest project among the 87 that make up WSIP. Almost all the other projects have been completed.

For WSIP and, in particular, Calaveras, SFPUC saw the need to identify and manage risk in a more systematic way than its informal risk-management process could handle. In 2009, Hou, then WSIP's risk manager, led the development of a risk register, which uses software to identify, assess and quantify risks, implement mitigation plans and other actions, and monitor and report results.

"People talk about risk all the time. But if you put it on paper, quantify it, make people own that risk—once they take ownership, it means they're going to make sure it won't happen," Hou says.

Led by AECOM, design of the dam began in 2003. Geological investigation, including more than 11,000 linear ft of geotechnical cores and dozens of test pits, revealed varying site conditions. Looking downstream, the left abutment comprises temblor sandstone, which tends to be quite pervious. Harder rock, known as the Franciscan complex, forms the valley floor and right abutment. These early investigations revealed two major challenges with the Franciscan rock: an ancient landslide at the right abutment and naturally occurring asbestos (NOA). These risks were identified in the bid documents, which specified mitigation strategies.

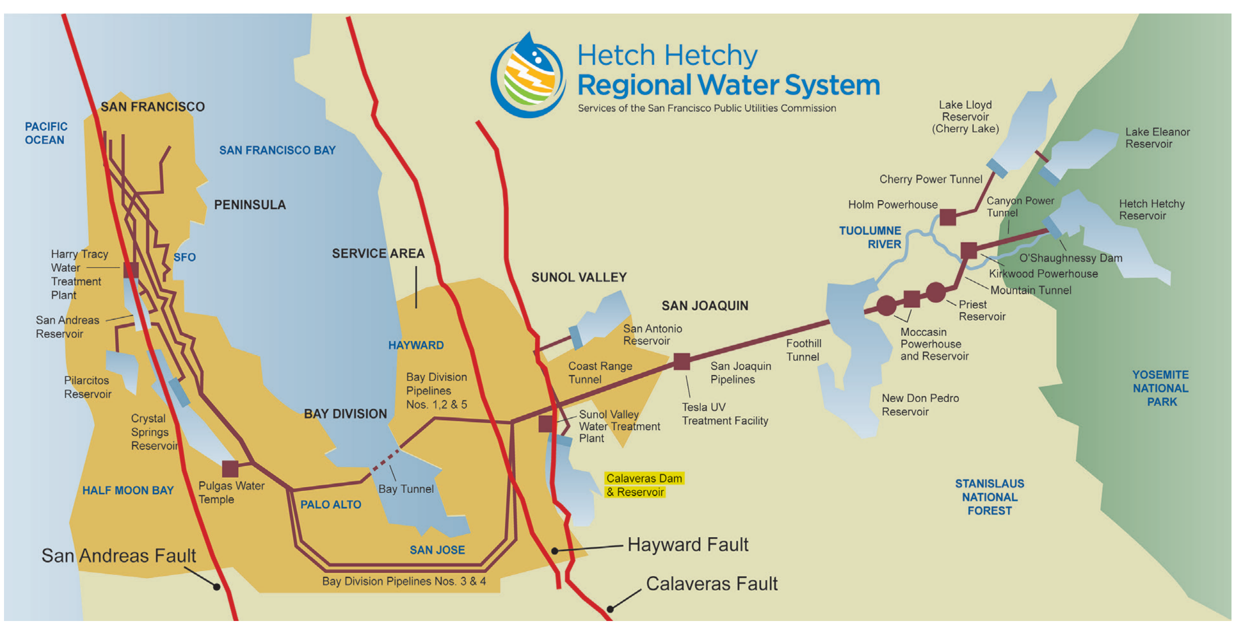
Joint-venture contractors Dragados USA, Flatiron West and Sukut Construction (DFSJV) mobilized on site in late 2011. Since the right-abutment landslide could destabilize once excavation began at the valley floor, crews tackled it early on by drilling and installing a soldier-pile wall. Once the downslope material was excavated, the soldier piles were tied back into the slope, creating a stable abutment.

When disturbed, the Franciscan material emits microscopic NOA particles. Aggressive measures are taken to protect workers' health. Before entering the site, each worker passes an eight-hour NOA training class. Areas containing NOA are restricted to authorized workers wearing varying levels of protection, from Tyvek coveralls to powered air-purifying respirators.

At the end of each shift, workers' boots are cleaned, and all clothing is vacuumed using HEPA filters. For any vehicle visiting any part of the site, its wheels and undercarriage are washed before it leaves.

Because drilling pulverizes rock and tends to create a high level of NOA particles, the contractor "tried various solutions to reduce the emissions with controls at the head of the drill, like shields, injecting water into the drilling apparatus and using foam-based additives to knock down the dust," says Dan Hernandez, the joint venture's NOA manager and a certified industrial hygienist with Flatiron. "We've even had HEPA vacuum trucks with enclosure boxes around the drill heads to ventilate the emissions out of the hole."

Although the team applies about one million gallons of water on the jobsite for daily dust control, the method's efficacy can be limited. Water typically is sprayed through a firehose



LIQUID GOLD The regional water system serves 2.7 million customers in the Bay Area. While 85% of water comes from Hetch Hetchy Reservoir located 167 miles to the east, Calaveras Dam provides most of the local storage for San Francisco.

MAP COURTESY SFPUC; PHOTOS BY ROBIN SCHESWOHL, COURTESY SFPUC

CLEAN SLATE An ancient landslide on Observation Hill required 1.6 million yd of additional excavation to mitigate. Once excavation wrapped up, crews performed exacting work using wire brushes (below) and HEPA-filtered shop vacs to prep the dam's foundation. Workers had to wear protective gear due to naturally occurring asbestos.

GEOLOGIC SHUFFLE
When dam construction ends, crews will breach the old dam with a 400-ft-wide channel. In November 2018 the reservoir will begin to be refilled. In the meantime, the contractor will complete site restoration and other work. By project completion in 2019, more than 10 million cu yd of earth will have been excavated.

PHOTO AND SCHEMATIC COURTESY SFPUC

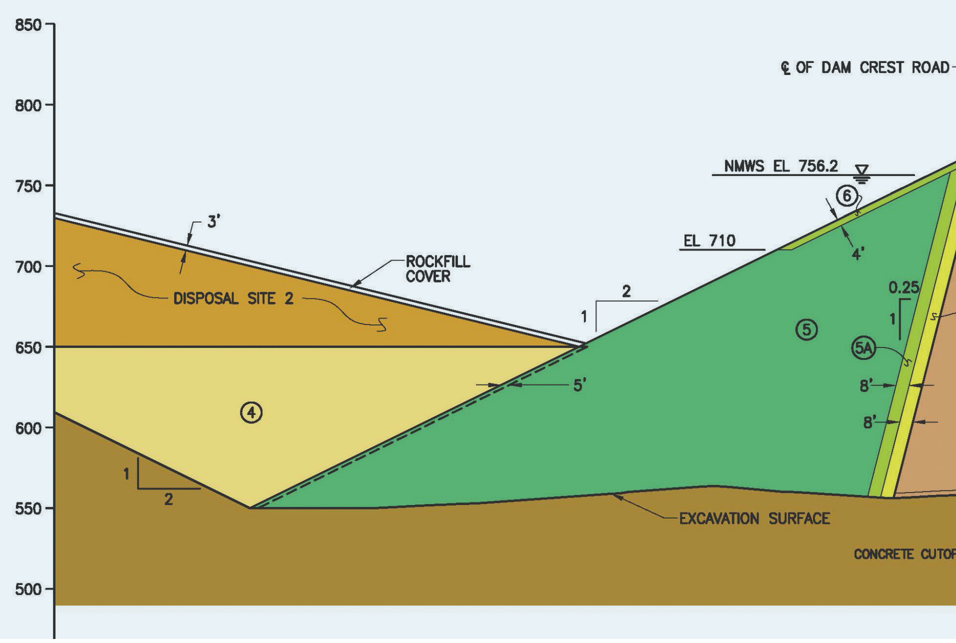
at 150 psi; however, the droplet nuclei are so large, the firehose can't tamp down the hydrophobic asbestos particles, which are one-tenth the diameter of a human hair. So, the team tried a method called condensation nuclei. "You humidify the airstream to 100% humidity, and [the airstream] condenses on the particle, causing [the particle] to grow in size enough so it is subject to impaction by larger water particles that we are spraying on," Hernandez says.

These evolving strategies highlight the flexibility of the risk-register system to evaluate and improve mitigation measures over time, Hou says. Numerous air monitors around the valley have verified that NOA emissions remain below strict limits.

Shaky Site Stability

Despite extensive geotechnical testing and careful risk tracking, in 2012, shortly after excavation of the left abutment began on Observation Hill, the project team uncovered an-

ZONE	DESCRIPTION	MATERIALS
1	DAM CORE	CLAY SOIL
1A	DAM CORE (AT FOUNDATIONS AND ABUTMENTS)	FINE CLAY SOIL
2	DOWNSTREAM FILTER	SAND
2A	FILTER	SAND AND GRAVEL
3	DRAIN	GRAVEL
4	DOWNSTREAM SHELL, RIGHT ABUTMENT BUTTRESS AND EXISTING SPILLWAY FILL	EARTHFILL
5	UPSTREAM AND DOWNSTREAM ROCKFILL SHELL	ROCKFILL
5A	COARSE FILTER	FINE ROCKFILL
6	RIPRAP	ROCKFILL



other ancient landslide that had evaded detection. The team halted excavation due to safety concerns; during a four-month period, additional investigations revealed that the massive slide required a total redesign of the left abutment.

"As soon as we found the issue, the city was very clear with its directions: 'Let's not talk about whose fault it is. Let's just focus on how to get these issues resolved together as a team,'" Hou says.

Originally designed as a 1.3:1 horizontal-to-vertical slope, the redesign flattened the slope to 2:1, ensuring long-term stability above the future dam and spillway, says John Roadifer, project engineer with AECOM.

The revision required 1.6 million cu yd of additional excavation, which had to be hauled and disposed. In addition, 1.4 million cu yd of the material, originally sequenced to be placed directly into the downstream shell of the new dam, now had to be stockpiled elsewhere first. Resequencing the project to accommodate the double-handling and extra excavation added two years to the construction schedule.

From the beginning of the project, SFPUC implemented formal partnering to foster teamwork through frequent sessions. In addition, a dispute-resolution board proactively meets with the project team once a quarter to facilitate communication, even though no formal claims have been filed on the project.

The partnering program is "one of the main reasons that we were able to work through these huge changes that added a significant amount of time and cost," says Mike Mulich, DFSJV construction manager. "Without a contract or a solid number in place, we decided as a group to move forward with the work and trust that we were going to be able to resolve the contractual dollars and time elements and agree on a schedule eventually."

Once excavation reached downslope to where the top of the dam would be built, geologists discovered yet another ancient landslide. Since it was located where the spillway would be built, it had to be removed in its entirety, adding yet another year to the schedule.

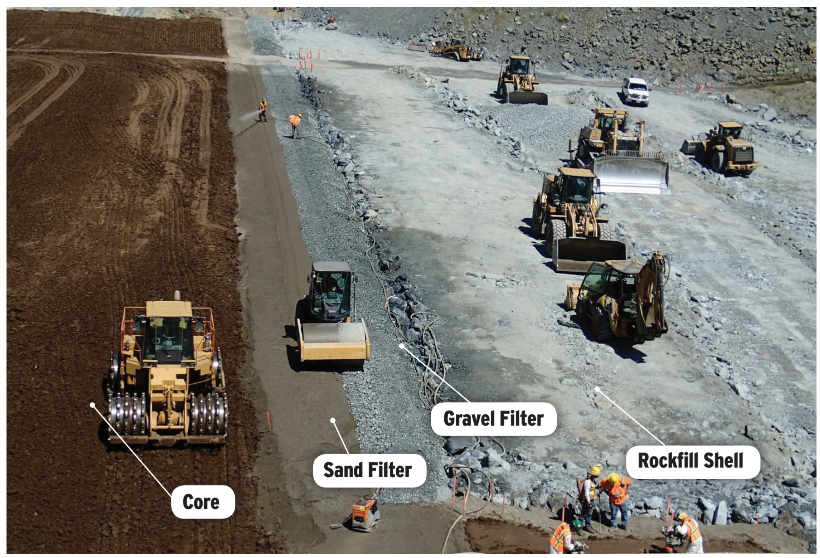
"Teams that are not as committed to partnering would have been completely derailed, and there would have been lawyers involved," Mulich insists.

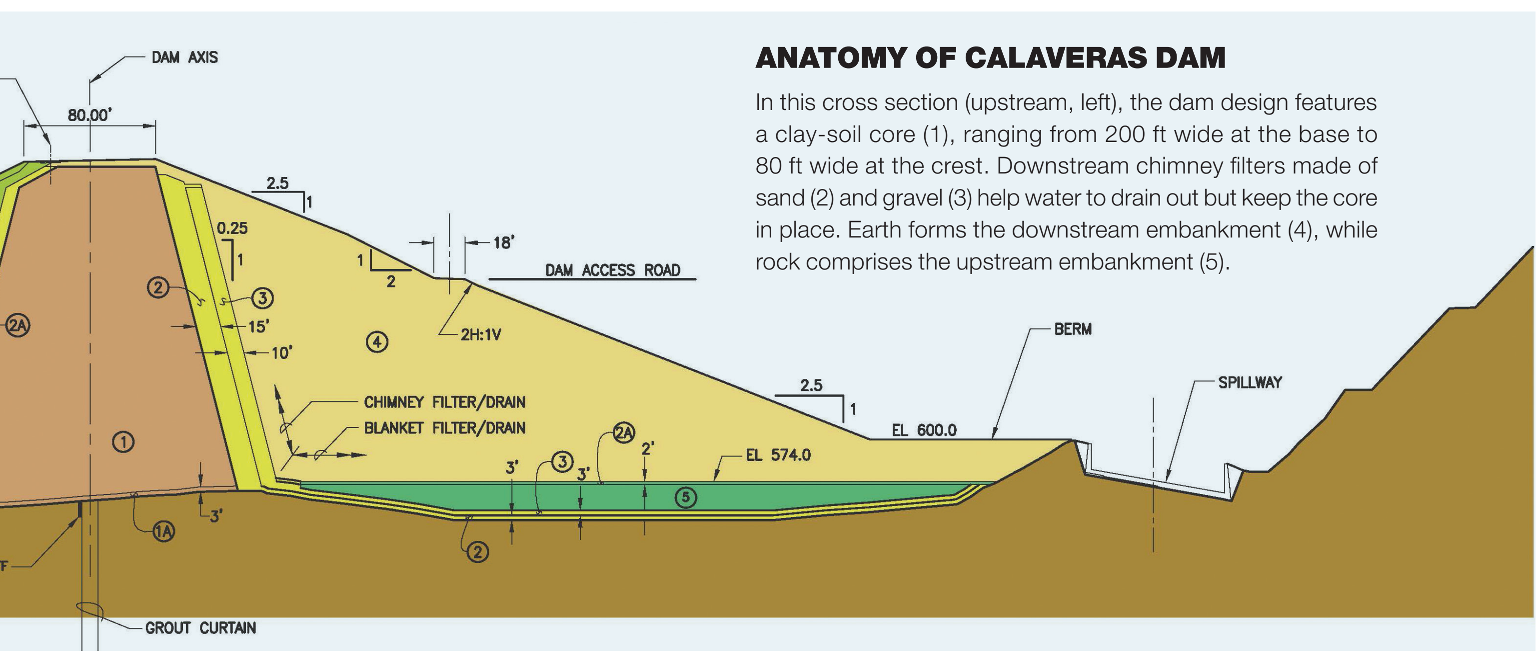
The SFPUC also used a technical advisory board, comprising four to six construction experts, to provide guidance. In addition, GEI Consultants conducted a postmortem third-party audit that determined the design team had performed proper due diligence in its geotechnical site investigation, Wade says.

"Yes, the project is a lot more expensive than we originally conceived of it as a result of the slide," Wade notes. "Had we known about it prior to construction, the project would still be about the same cost. The reality is, this is the only place that the dam can go."

PHOTO COURTESY SFPUC

EARNING STRIPES
Each zone of the dam requires a specific material, such as sand or gravel, in a specific size gradient. Placement requires GPS-controlled grader blades and meticulous work.





ANATOMY OF CALAVERAS DAM

In this cross section (upstream, left), the dam design features a clay-soil core (1), ranging from 200 ft wide at the base to 80 ft wide at the crest. Downstream chimney filters made of sand (2) and gravel (3) help water to drain out but keep the core in place. Earth forms the downstream embankment (4), while rock comprises the upstream embankment (5).

SEWER PROGRAM ADDS BILLIONS

Like its cousin WSIP, San Francisco's 20-year Sewer System Improvement Program (SSIP) addresses the perilous state of the city's sewer infrastructure, upgrading the century-old system that serves more than 800,000 customers.

The $6.9-billion program will upgrade aging, seismically vulnerable gray-water infrastructure, such as pump stations and treatment facilities, build green infrastructure to reduce stormwater flows into the sewer system and incorporate resilience against climate change.

Phase one of SSIP, which began in 2012 and costs $2.9 billion, includes 70 projects in various stages of planning and construction. Projects range from replacing treatment facilities to building a new 24-ft-dia gravity tunnel to convey wastewater. Eighteen of the projects are currently under construction, with 13 completed and the remainder in design or heading for construction bids, says program director Karen Kubick.

The two biggest projects—the biosolids digester and headworks projects at the city's Southeast Treatment Plant—cost $2 billion alone. Built in 1952, the plant has operated continuously for 65 years and cannot be closed during construction, Kubick says.

Slated to begin construction next year, the biosolids project will replace and relocate outdated solids-treatment facilities with more reliable, efficient and modern technologies. The new plants are designed to produce higher-quality biosolids and control odors as well as maximize biogas use and energy recovery to produce heat and steam energy.

Crews on the headworks project will replace the plant's two headworks facilities, since the existing plant can't adequately screen grit, debris and sand, causing odors and affecting downstream equipment. Further, the project will improve the pump station.

SSIP's green infrastructure projects include planting rain gardens, redesigning streetscape features and redirecting a creek on the city's southeast side to an aboveground channel. Building green infrastructure brings its own challenges, Kubick says, adding, "It's been almost like a start-up. Our designers had to learn how to design this and train local contractors how to build green infrastructure." ■

By Christine Kilpatrick

UPGRADE San Francisco will replace biosolids digester facilities at southeast plant.

PHOTO COURTESY BROWN & CALDWELL

In total, the project will excavate around 10 million cu yd of earth and rock, reusing about 3.5 million cu yd in the 1,210-ft-long dam. The remainder will be distributed at various sites around the valley, including between the old and new dam.

Shell Game

The team resequenced other work around the multiyear left-abutment excavation. Grouting work, an essential step that fills in cracks and fractures in the dam's foundation bedrock and prevents water from seeping underneath the dam, typically starts at the bottom of a valley floor and works up the slopes. However, since the Calaveras creekbed couldn't be excavated until the left abutment was completed, grouting was performed out of sequence, says Jim McClain, construction manager with Black & Veatch.

Crews also constructed a 20-ft-dia, 163-ft-deep intake tower, located on the existing dam, to replace the seismically deficient old tower, which was later demolished. Three adits and a drain at varying levels were connected from the new tower to the existing outlet-works' piping.

Once excavation was complete in early 2015, crews extended the old outlet pipe with new 78-in.-dia steel pipe encased in reinforced concrete. The new outlet pipe will connect to a city pipeline to deliver water to a downstream treatment plant.

The team also built the spillway and, just below it, an approximately 60-ft-high, 800-ft-long tieback wall. So far, more than 7,000 anchor bolts have been placed on the project. Since some of the spillway's foundation rock had to be removed due to the ancient landslides, crews placed more than 18,000 cu yd of backfill concrete in thicknesses up to 35 ft, providing a stable platform for the spillway. At 60 ft wide and 1,550 ft long, the spillway itself required 41,600 cu yd of concrete.

Before crews could start taking the dam vertical, the foundation rock needed to be cleaned and prepped. "There's a massive amount of hand labor that happens," Mulich says. "Once you get down to cleaning the foundation, there are workers on their hands and knees with little picks, wire brushes and shop vacs to clean and start dam construction at the level of cleanliness that the specifications require."

The foundation is so clean, "it's almost like you could eat off it," says Roadifer, adding that it provides good bonding between the dam's clay core and the bedrock.

Finally, in 2016, DFSJV could begin to assemble the intricate dam structure. At 1,180 ft at its base, the broad, triangular-shaped dam includes many different zones of varying sizes of rock, sand, clay and earth particles—each chosen to provide seismic strength and prevent water seepage.

At the center, a core of clay soil ranges from about 200 ft wide at the base to 80 ft wide at the crest. On the upstream side of the core, two 8-ft-wide chimney filters—one made of course, 4-in. rockfill and the other of sand and gravel—help to keep the core in place. The downstream side also features two chimney filters, which are "the zones that are most critical in the dam in some respects," Roadifer says. A 15-ft-thick sand filter and a 10-ft-wide gravel filter protect the core from eroding out of the dam in the event of water penetrating any cracks in the core after a seismic event. The sand allows water to come through but blocks the clay particles, while the gravel chimney acts as a funnel and allows water to fall quickly to the drain layers at the bottom of the downstream side of the dam.

The broad downstream embankment incorporates earth removed during the left-abutment excavation, while the upstream embankment employs 30-in.-maximum rockfill to protect the dam where the reservoir acts directly against it.

To allow for possible future expansion, the core and filters are being built much wider than needed. The dam could be raised by an additional 150 ft, quadrupling the reservoir's storage capacity, Wade says.

To assemble this complex, sideways layer cake, DFSJV runs two 10-hour shifts. The various materials are brought in, sized, sorted, stockpiled and then placed in 1-ft-thick increments before being compacted. The grading equipment blades all feature GPS controls to maximize efficiency of the placement operation, Mulich says. The coordinates are compared against a detailed 3D model, derived from high-resolution site scans after the foundation was cleaned and prepped.

With limited road space to the valley floor, the contractor opted for a 3,800-ft-long conveyor system to bring 8,000 cu yd of downstream shell material to the site each day for placement. This tactic saves almost 400 truck trips in and out of the tight site, McClain says.

Nature's Last Parry?

Due to California's potentially wet winters, the jobsite typically shuts down from December to March. However, in the winter of 2016-17, with the dam assembly going full speed ahead, the team was scheduled to work straight through. Unfortunately, after many years of drought, the area was inundated by El Niño storms. The reservoir swelled, flooding a road used to truck in the clay soil for the core. Then, after a particularly intense storm, part of the main access road to the site collapsed—yet another landslide impacting the job. "That all but shut us down over the course of last winter," Mulich says. Despite the setback, he says crews made up the ground in 2017; currently, at about 60% completion, the dam structure is slightly ahead of schedule. "We believe that we could've been a little further ahead of schedule if we would've had 10 to 15 extra people available," but California's tight labor market and other dam projects, including Oroville's emergency-spillway reconstruction, have made it an "incredible challenge to man the project," he adds.

After this winter's scheduled shutdown, work will resume in mid-March 2018 to complete the dam by summer. Then, once part of the old dam is cut away to form a channel to the new dam, SFPUC will begin refilling the reservoir in November 2018 and finish up site restoration and other ancillary work by spring or summer 2019.

"Our operations folks are looking forward to getting this facility back on line," Wade says. ■

WATER SLIDE Due to material removed from the ancient landslide, crews had to backfill the bedrock with 18,570 cu yd of concrete to form the spillway foundation. The spillway itself required more than 41,000 cu yd of concrete.

PHOTO BY ROBIN SCHESWOHL, COURTESY SFPUC

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