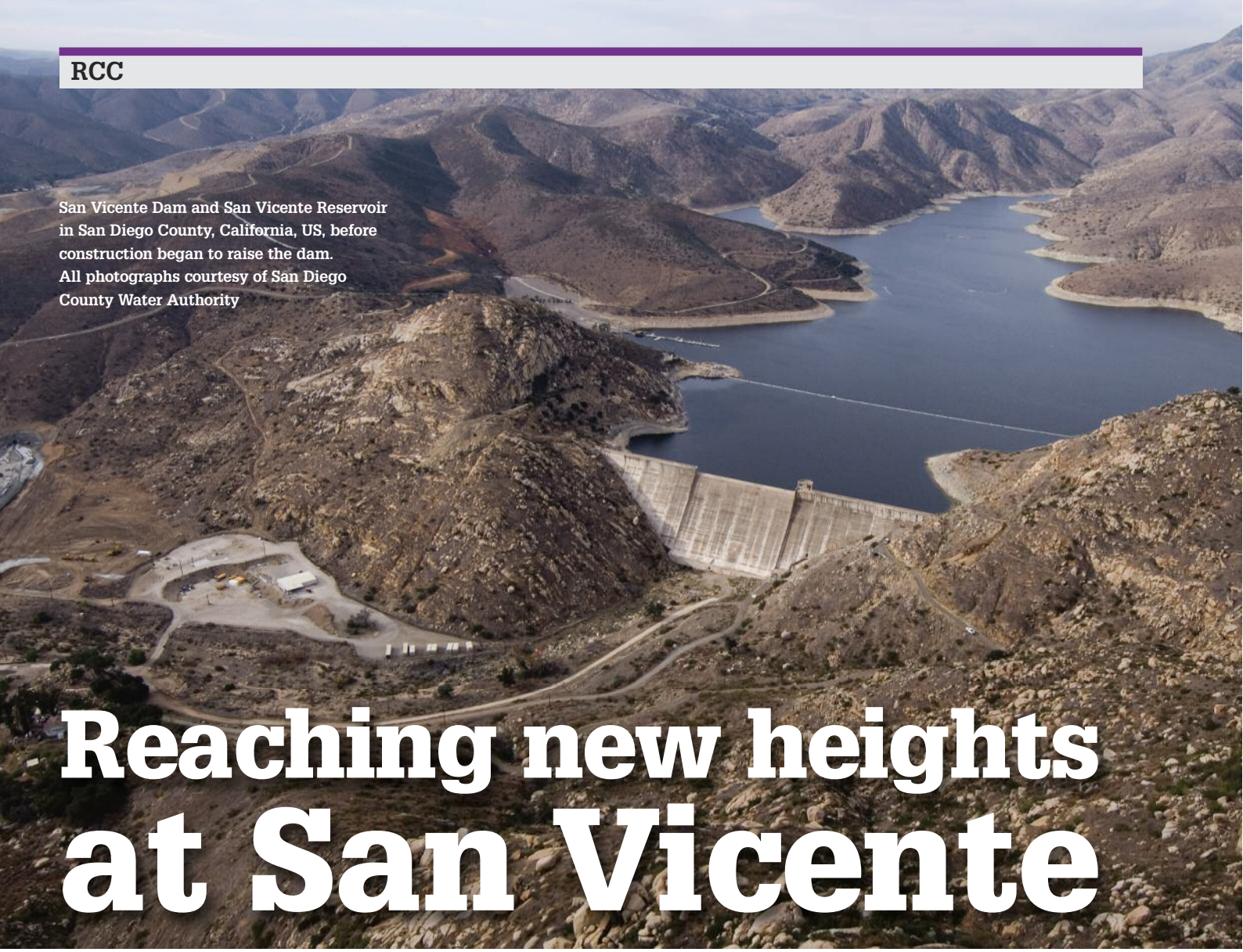
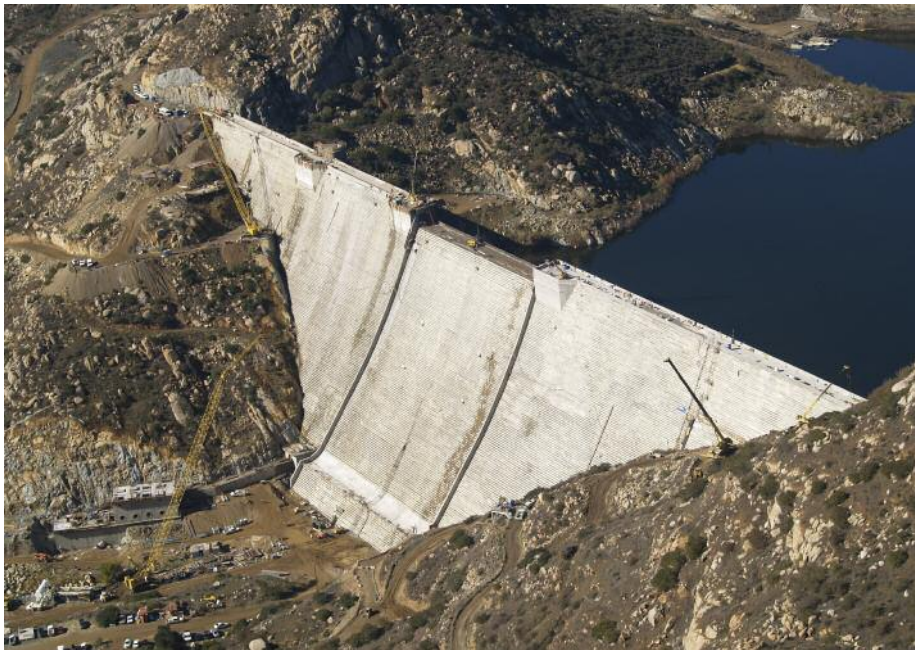


San Vicente Dam and San Vicente Reservoir in San Diego County, California, US, before construction began to raise the dam. All photographs courtesy of San Diego County Water Authority

Reaching new heights at San Vicente

As the San Vicente Dam Raise Project nears completion, Glenn S. Tarbox, Gerard E. Reed III and J. Wade Griffis provide details on the largest raise of a concrete dam in the US, and the highest raise using RCC in the world



Aerial view of the San Vicente Dam downstream slope after completion of the dam raise using RCC, giving an appearance of a concrete staircase.

San Diego County, California, currently imports approximately 80% of its drinkable water supply from over 400 miles away from the San Francisco Bay Delta of Northern California and the Colorado River to the East. In the event of a natural disaster, such as extreme drought or earthquakes, San Diego – the eighth largest city in the US – and its surrounding communities could be cut off from its essential water supplies.

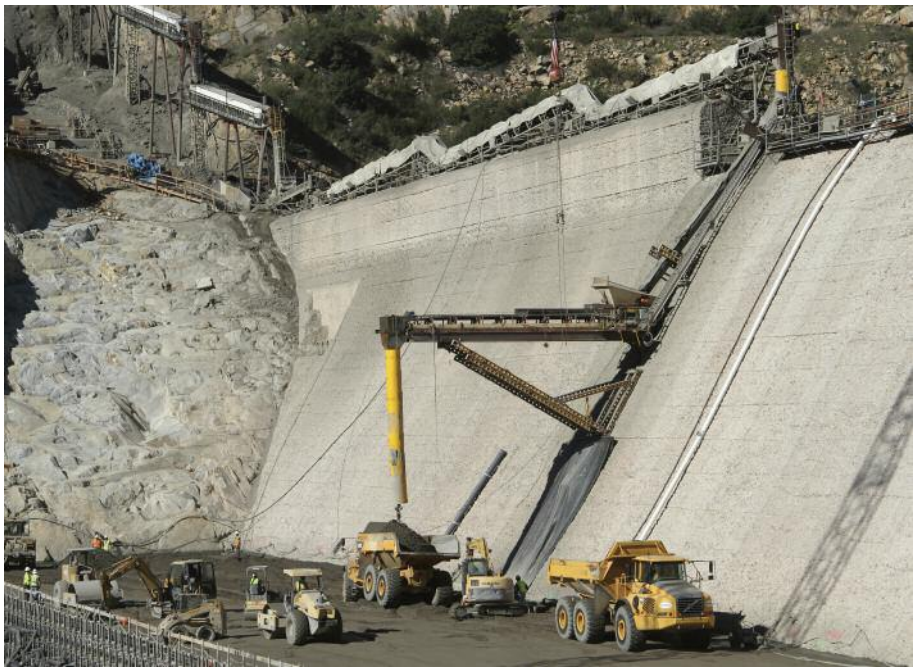
In an effort to address this concern and increase regional critical emergency water storage, the San Diego County Water Authority set out to raise the existing 70-year-old San Vicente Dam, owned and operated by the City of San Diego, from 220ft (67m) high to 337ft (102.7m) high, thus more than doubling the size of the reservoir by adding 152,000 acre-ft of water storage capacity – equivalent to more than 49 billion gallons of water – or an increase of 170%. Filled to capacity, the raised dam will provide a reservoir for normal water supply, plus room for emergency and carry-over supplies of water. Carry-over water is stored during wet periods of

excess water and made available for use during dry years.

The San Vicente Dam Raise is the largest project of the Water Authority's $1.5B Emergency Storage Project (ESP), a system of reservoirs, interconnected pipelines and pumping stations designed to make water available to the San Diego region in the event of an interruption in imported water deliveries.

Once complete, the ESP, which has been under way for more than a decade, will add new reservoir storage in San Diego and will expand the existing transmission and distribution capabilities, providing up to a six-month emergency supply of water.

The construction on the dam is scheduled to be complete by the end of 2013. Between 2015 and 2017, when all phases of the associated site projects are slated to be complete and based upon imported water supply availability, the San Vicente Reservoir will be reopened to recreational use. When full, the reservoir will hold up to a year's worth of water reserves for 300,000 households.

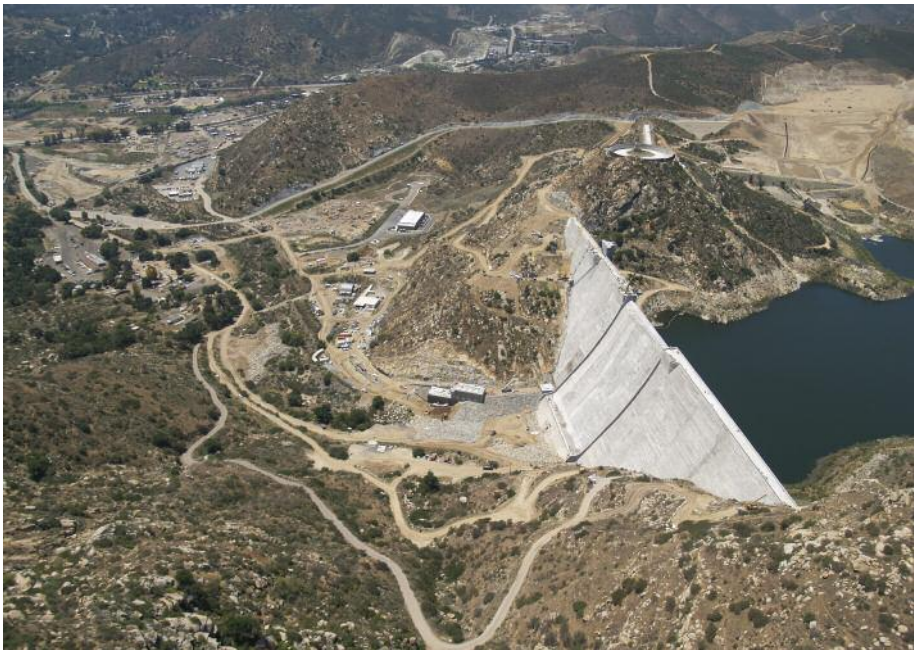


A conveyer system was used to transfer the RCC from the onsite batch plant to the dam.

RCC approach

The San Vicente Dam is a concrete gravity dam located 20 miles west of San Diego near Lakeside, California, and was originally constructed by the City of San Diego from 1941 to 1943 to meet the needs of the region's growing population. In the past seven decades, San Diego County's population has swelled from about 500,000 to 3.1 million residents with a $188B local economy. More than 70 years after the original dam was constructed, the continued growth of the San Diego area meant the dam required a face lift – quite literally.

In 2006, as part of its overall Emergency Storage Project, the Water Authority selected Broomfield, Colorado-based MWH Global through a competitive request for proposal process to provide final design and engineering work for the San Vicente Dam Raise project. The scope of work includes quarry design, design construction support, value engineering and cost estimating. The construction phase of the project was executed in several distinct packages, including quarry and roller-compacted concrete (RCC) mix testing (Package 1), foundation excavation (Package 2) and then RCC dam construction (Package 3). The multi-package approach allowed some construction work to be started while the design was completed for the major project features. The Water Authority utilized the services of a joint venture between Black & Veatch and Parsons Corporation for construction management of the dam raise.



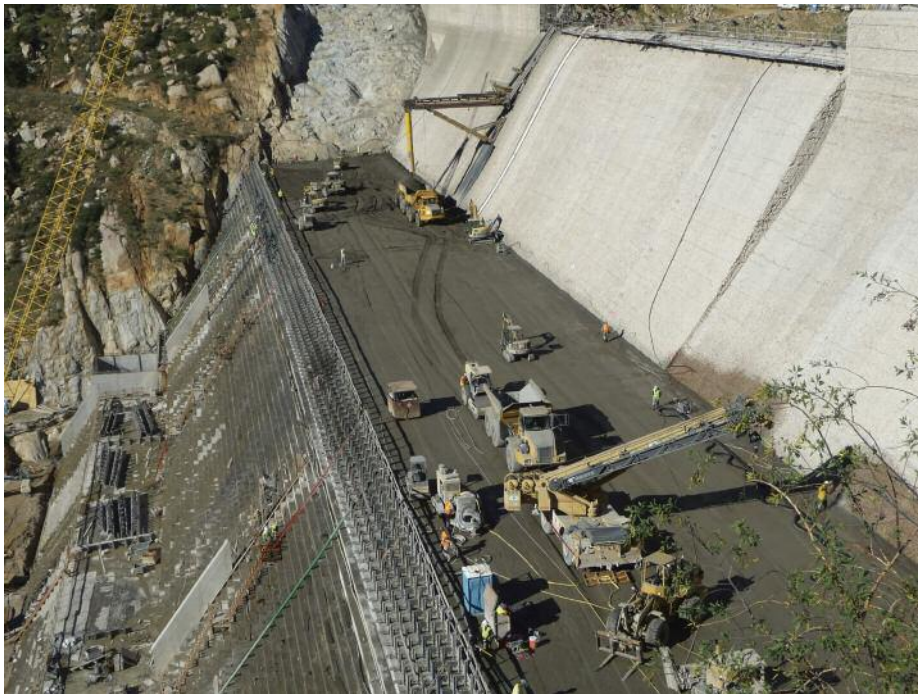
Pictured in the top right corner is the source of the aggregate for the RCC and the location of the future marina.

The early planning team, headed by GEI Consultants, selected a RCC method to lift the existing dam by 117ft (35.7m). In fact, according to a report by the American Concrete Institute, RCC is one of the most important developments in concrete dam technology in the past quarter century.

For the San Vicente Dam Raise, the RCC method offered significant advantages. The final design team optimized the use of on-site aggregates to reduce costs and develop a concrete mix that closely matched the physical properties of the original dam structure. Extensive testing of both the existing dam materials as well as the RCC materials for the new dam (Package 1) confirmed the expected performance of the structure under normal and extreme seismic conditions.

Due to the proximity of mined rock, RCC was among the most attractive options. By using this method, 90 percent of the RCC's main ingredient – concrete – was produced on site with rocks mined from the hillsides circling the old recreational marina less than half a mile away. This use of on-site resources helped avoid more than 100,000 delivery truck trips through the local Lakeside community.

RCC has the same basic ingredients as conventional concrete, but in different ratios resulting in a much drier, zero-slump mix. Conventional concrete would have been much more expensive and time consuming due to the high ratio of man hours to concrete volume placed for labor-intensive activities, such as face forming, joint preparation, and concrete consolidation with



The RCC placement proceeded nearly continuously, enabling the contractor to work on the RCC immediately after it is laid, allowing the 600,000 cubic yards of dam raise concrete placement to be completed in less than a year.

internal vibrators. On the other hand, RCC offers a lower ratio of man hours thanks to the mechanical equipment used to spread and compact the mixture resulting in less forming and joint cleanup.

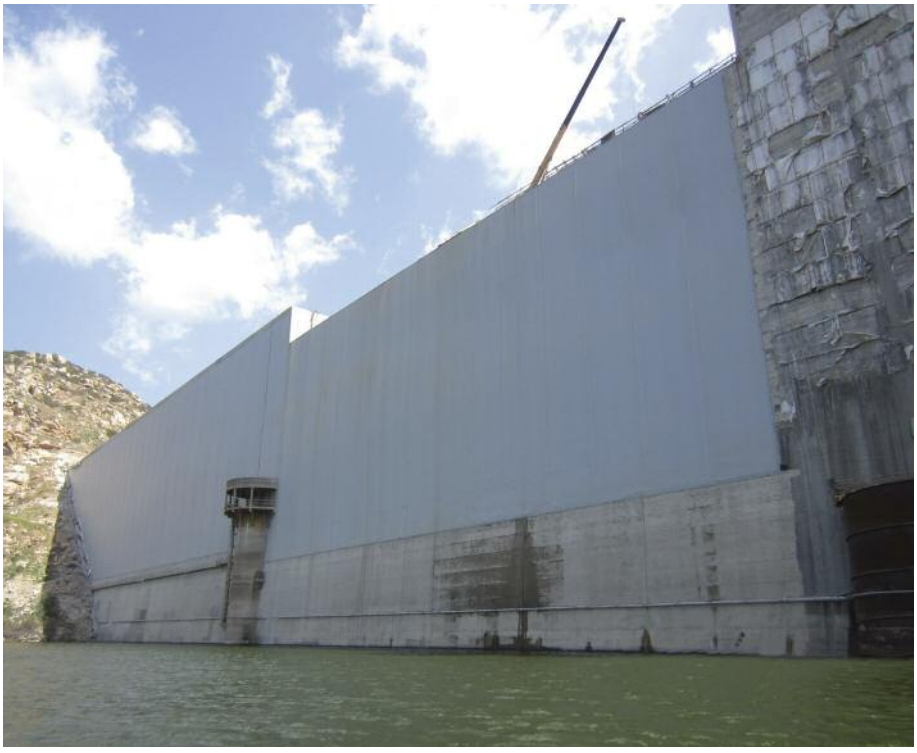
In addition to the benefits of the RCC method, it is a proven process. The California Division of Safety of Dams was comfortable with this approach because this method was successfully used just over five years earlier as part of the construction of the new 320ft (97.5m) high Olivenhain Dam, also located in San Diego County. This dam was one of the Water Authority's first projects in its plan for increasing the San Diego region's water storage capacity. Completed in 2005, MWH Global also engineered the dam using RCC design. The Olivenhain Dam and Reservoir project was recognized and awarded by International Commission on Large Dams (ICOLD) as one of the milestone projects over the 30-year period of modern day RCC dams from 1980 to 2010. It also holds a record as one of the top-four fastest, average monthly (121,896m^3) and peak placement rates (224,675m^3) of RCC worldwide. It has a total volume of 1,070,000m^3.

Many design and construction lessons learned at Olivenhain Dam were applied at San Vicente to the overall benefit of the owners, including the choice to adopt the RCC methodology for raising the dam, the construction packaging approach, and onsite quarry and batch plant for producing aggregate and RCC.

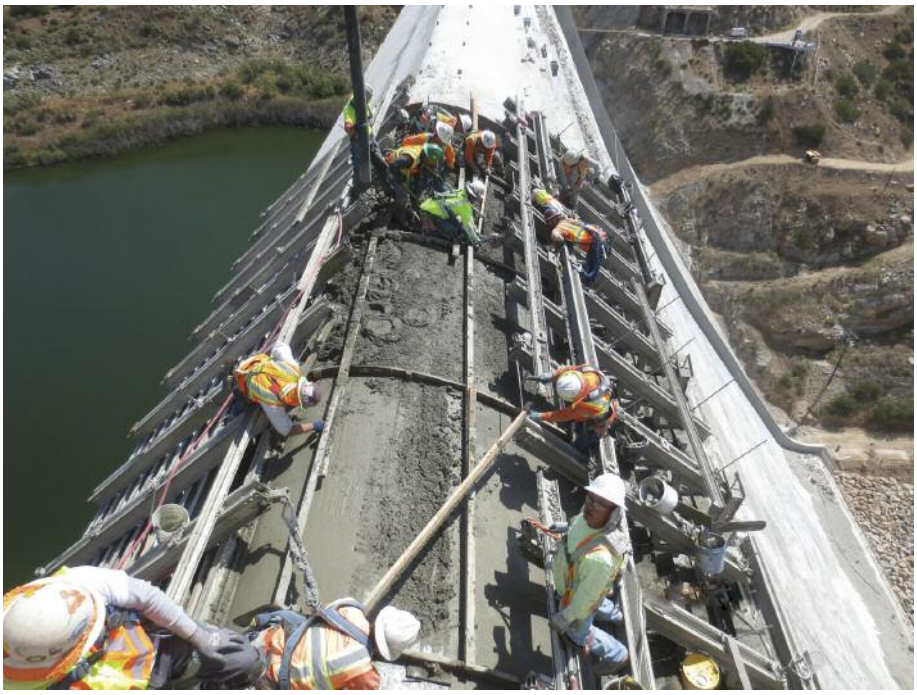
Raising the dam

Following the planning and final design stages, construction to raise San Vicente Dam began in the summer of 2009. The first phase of construction (Package 2) started with foundation excavation, which also included removing two to three inches of concrete from the downstream side of the dam to create a strong concrete bonding surface between the original dam and the planned raised dam. This material was removed using high-pressure water jetting to ensure that there would be no structural damage to the concrete left behind on the existing dam. The resulting exposed aggregate finish of the existing dam provided a sound, irregular surface to which the new RCC could strongly bond. The foundation excavation was accomplished with the use of controlled blasting to remove the surficial materials to exposed competent rock. In addition, this construction package included the mining of a 10ft (3m) diameter tunnel through the existing dam to prepare the structure for the installation of a new low-level outlet system required by the Division of Safety of Dams for emergency reservoir evacuation, which was not included in the original dam's construction.

The existing marina area was transformed into a large quarry operation complete with a batch plant for mixing RCC. The RCC material was transported less than half a mile to the dam and placed on the downstream side of the existing dam up to the original dam's crest, then extended 117ft (35.7m) higher to complete the raised dam. The RCC zero-slump material was transported via conveyors and placed with trucks and dozers. The material was placed in 12-inch horizontal layers giving the appearance of a staircase on the downstream slope of the dam. The first layer of concrete for the foundation of the dam raise was placed in September 2011 and the original dam height was quickly reached by May 2012. The final height of the dam was reached in September 2012. More than 600,000 cubic yards were placed



The San Vicente Dam was raised 117ft (35.7m), the highest dam raise in the U.S. and tallest dam raising use RCC in the world. Visible in the center of the dam is the original control tower. The raised dam section shows the upstream Carpi geomembrane liner.



The construction crew smoothed the top of the new spillway.

in the raised dam and a small saddle dam needed to close a topographic low in the reservoir rim near the marina.

The final RCC design had specified using the raw concrete materials from the borrow pit upstream of the dam to match the material properties of the aggregates used in the original dam construction. Once completed, the two bodies of concrete will function together as a single structure under normal and extreme conditions. Daily laboratory material tests confirmed that each batch of concrete met strength and performance specifications. This was a considerable advantage particularly from the thermal characteristic point of view because not only did the RCC aggregate material function to best match the thermal characteristics of the dam, the rock was easily excavated from its conglomerate formation with expensive blasting.

When the dam reached its final height of 337ft (102.7m) in September 2012, it marked the largest raise of a concrete dam in the U.S. and the highest raise of a concrete dam using RCC in the world. Official completion is expected to be achieved late in 2013 when the new outlet works and instrumentation are complete and ready to begin controlling the flow of water out of the reservoir. The final work on the dam will be accomplished under Package 3.

Although the San Vicente Dam Raise project reaped the benefits of using lower-cost RCC, each site must be evaluated for conditions which control the RCC material costs – conditions such as: 1) availability of coarse and fine aggregate materials, 2) suitable strength of foundation rock for a concrete dam, or 3) local faulting or differing foundation conditions, which may lead to excessive differential settlement.

Environmental aspects

As with many water infrastructure projects, engineers needed to consider environmental aspects and implications of the dam raise.

The environmental concerns evaluated as part of the San Vicente Project included clean air and water and several threatened species. To control water and air pollution, engineers provide strict project specifications to control the site according to the approved permits and local regulations. The coastal California gnatcatcher, a songbird found in Southern California and currently listed as a threatened species by the US Fish and Wildlife Service, makes its home near the San Vicente site. The Water Authority and contractors provided protection for these sensitive species by coordinating all on-the-ground construction and maintenance practices.

To minimize environmental impacts to the project site as a result of the quarry operations, the borrow pit and quarry pond area was developed upstream of the dam in the future reservoir location. The waste materials from the quarry operations were used to develop the mass fill for the new parking lot and boat ramp upstream of the dam to avoid additional costs for waste disposal and new excavations to generate the required fill volumes. This strategy yielded a balanced site and helped to minimize truck traffic through the local community, as mentioned.

Later phases

Additional work will continue until 2015 to build a new recreational marina and a replacement pipeline for the City of San Diego. While the reservoir has remained open to commercial customers during construction, it has been closed for recreational use since 2008. Approximately 50,000 acre-feet of water must be added to the reservoir to open the marina to the public after construction is completed. The marina opening date is dependent upon the availability of the 50,000 acre-feet of imported water.

The San Vicente Dam Raise Project will more than double the size of the original marina facility at the San Vicente Reservoir, a popular destination for local water sports enthusiasts. A six-lane boat ramp, new docks, additional parking, new service buildings, picnic tables and shade structures will also be constructed as the existing marina will be inundated by the expanded reservoir's water level.

The San Vicente Dam Raise is only one of the several projects included in the Water Authority's Emergency Storage Project, which will add a total of 90,100 acre-feet of water storage for emergency use. Other projects included:

- Lake Hodges Project – a connection from Hodges Reservoir to Olivenhain Reservoir to provide a water storage capacity of 20,000 acre-feet;
- Olivenhain Dam and Reservoir – San Diego region's first new dam and reservoir in 50 years to provide a water storage capacity of 24,000 acre-feet;
- San Vicente Pipeline – an 11-mile pipeline to deliver water from the reservoir to the central and southern half of the county; and
- San Vicente Pumping Facilities – facilities to move 300 million gallons of water from the reservoir through the pipeline to the Water Authority's water delivery system.

The RCC method enabled an efficient, economical and effective approach to raising the San Vicente Dam, doing its part toward meeting the region's emergency water storage needs. ■

Author information

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J. Wade Griffis is the lead construction administrator at San Diego County Water Authority.