As part of its efforts to combat seawater intrusion, ensure adequate water for irrigation, and reduce demand for groundwater, the Monterey County Water Resources Agency recently constructed the Salinas River Diversion Facility. However, before construction work could begin on the diversion dam, the design had to address important geotechnical concerns, including the presence of loose, liquefiable soils with significant scour potential. The site required special foundation designs and remedial measures to ensure structural stability under seismic and flood loads.

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LOCATED JUST UPSTREAM of Monterey Bay near the coastal town of Marina, California, the Salinas River Diversion Facility (SRDF) is making a significant contribution to efforts by the Monterey County Water Resources Agency (MCWRA) to combat seawater intrusion in an important agricultural area. Project components include a diversion structure featuring inflatable gates, an intake structure with fish screens, a pump station, a transmission pipeline connecting to an existing distribution pipeline system, and a fish ladder with vertical slots. However, before construction work on the recently completed project could begin, the design had to address important geotechnical concerns, including the presence of loose, liquefiable soils with significant scour potential. The site required special foundation designs and remedial measures to ensure structural stability during seismic and flood events. Addressing these geotechnical issues enabled the MCWRA to proceed with its plans to secure adequate water for irrigation while helping to reduce demand for groundwater. The completed project also improves fish passage conditions along the Salinas River upstream of the site and includes measures to protect migrating fish during diversion operations.

The Salinas River valley, a highly productive agricultural area on the central California coast, extends nearly 100 mi inland from Monterey Bay to Paso Robles. Historically, coastal area growers relied on pumped groundwater to meet their irrigation needs during the normally dry summer and fall seasons. Beginning in the 1930s, this pumping caused seawater intrusion into coastal aquifers, eventually rendering portions of the aquifers excessively saline and unusable for irrigation. In response, the MCWRA, the entity responsible for water supply throughout most of the valley, initiated a series of projects in the 1990s to reduce groundwater pumping and provide alternative methods of water delivery to the affected areas.

In 1996 and 1997, the MCWRA constructed the Castroville Seawater Intrusion Project (CSIP), which consists of a tertiary recycled water treatment plant, a distribution pipeline system located close to the coast in the intrusion area, and a series of supplemental groundwater wells located outside the intrusion area. However, after the CSIP was completed, irrigation demands continued to increase, and groundwater pumping continued when needed to meet peak demands. To further reduce the use of groundwater in the area served by the CSIP, the MCWRA initiated the Salinas Valley Water Project in 2002. That endeavor comprised three main elements:

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The Salinas River Diversion Facility includes a diversion structure featuring inflatable gates, an intake structure with fish screens, a pump station, a transmission pipeline connecting to an existing distribution pipeline system, and a fish ladder with vertical slots. Because of the presence of loose, liquefiable soils with significant scour potential, the site required special foundation designs and remedial measures to ensure structural stability, particularly during seismic and flood events.

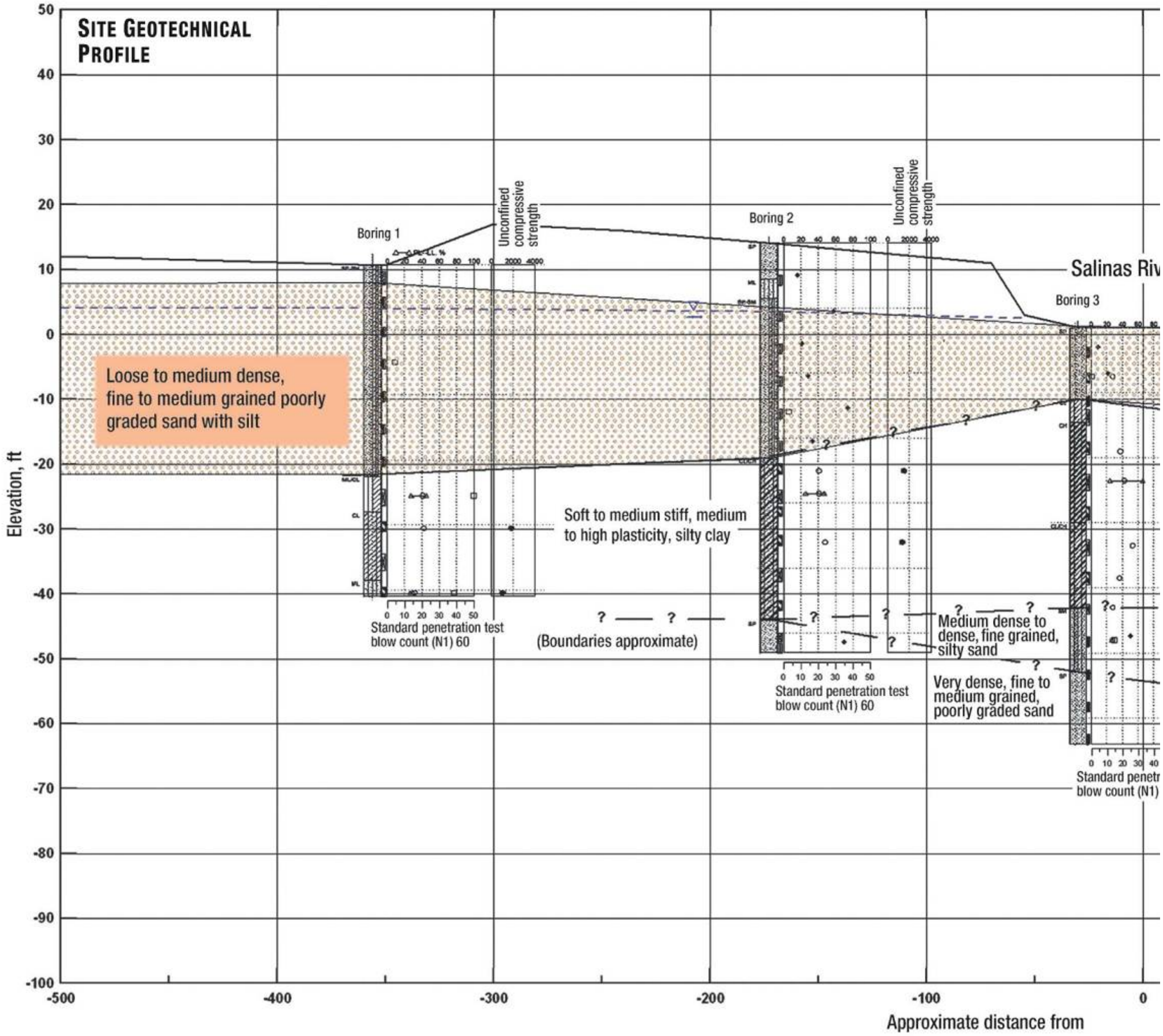
MCWRA, ALL PHOTOGRAPHS

changes to the rules of operation for the upstream Nacimiento and San Antonio reservoirs to increase irrigation season releases, modification of the dam spillway at Lake Nacimiento to permit increased winter season carryover storage (and corresponding summer releases), and construction of the SRDF.

The SRDF project site is located several miles inland from the mouth of the Salinas River on the main channel. During the irrigation season, additional water will be released from the MCWRA's upstream Nacimiento reservoir into the river. Besides recharging groundwater throughout the valley, this water will flow downstream for about four days (through what would normally be a dry riverbed) before reaching the SRDF site. The 9 ft high inflatable gates at the diversion structure will create a detention pond with a volume of approximately 100 acre-ft. From the detention pond, the river water will pass through intake screens into a pump station that has a design capacity of 35 cfs (or 23 mgd). The water will be conveyed for 1 mi through a 36 in. diameter pipeline to a filtration station before it enters the CSIP pipeline system. The water supplied by the SRDF will offset the need for groundwater pumping and will increase the ability of the CSIP to meet peak irrigation flow demands.

A preliminary design study for the SRDF project was completed in 2003. In 2005 the MCWRA retained the URS Corporation, of San Francisco, as part of a final design team led by the Boyle Engineering Corporation, Inc. (Boyle Engineering has since been acquired by AECOM, of Los Angeles.) URS was responsible for geotechnical and earthquake engineering, studies relating to river hydraulics and flood effects, and the design of the diversion dam, intake structure, and fish passage facilities. In addition to providing overall project management, Boyle Engineering designed the pump station and transmission pipeline facilities. The final design was completed in early 2008. Construction began in the spring of 2008 and was completed in the winter of 2009. The project went into service this past spring.

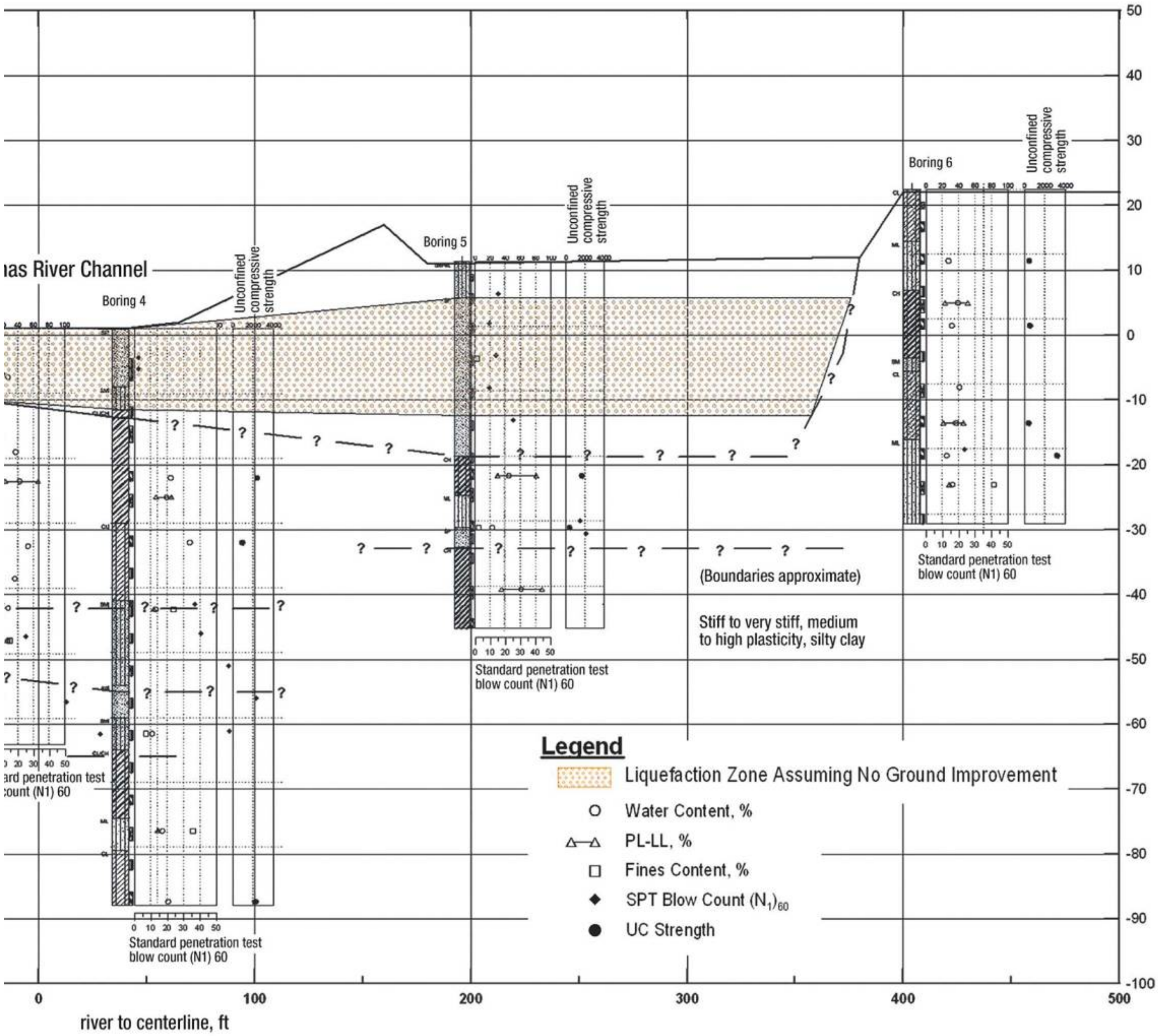
The MCWRA conducted a thorough environmental review process for the SRDF project. On the basis of the results



of that process and of discussions with key state and federal permitting agencies, important elements of the facility design and operational plans were optimized. One key driver of the project is the fact that the Salinas River provides critical habitat for the central California coast steelhead (*Oncorhynchus mykiss*), which is classified as a threatened species under the federal Endangered Species Act. During normal operations, the diversion structure gates will be raised only during the irrigation season, from about April through October. However, since fish migrations can still occur within this time frame, the intake structure is equipped with intake screens that are sized to protect small fish that might be present in the detention pool. The diversion structure also includes a fish ladder to enable larger fish to move upstream. The operating criteria for the diversion structure will allow both upstream and downstream fish migrations to proceed during periods when the gates are raised. The overall project will enhance the opportunity for fish passage in the Salinas River as a result of the additional flow releases from the upstream reservoir during normally dry periods.

The primary components of the SRDF in the river include a diversion dam structure with a variable regulating gate bay and inflatable gates, an intake headwall structure with removable fish screens, and a fish ladder with vertical slots and hydraulically operated flow control gates (see the figure on page 74). Project components located adjacent to the river channel include the pump station, scour and erosion control measures, and the transmission pipeline leading to the CSIP distribution system.

The Salinas River is subject to major winter flooding, especially in the downstream reaches near the Pacific Ocean. Therefore, the SRDF design criteria required a diversion structure that could be lowered or removed entirely during the winter. Traditionally, many such seasonal diversion dams

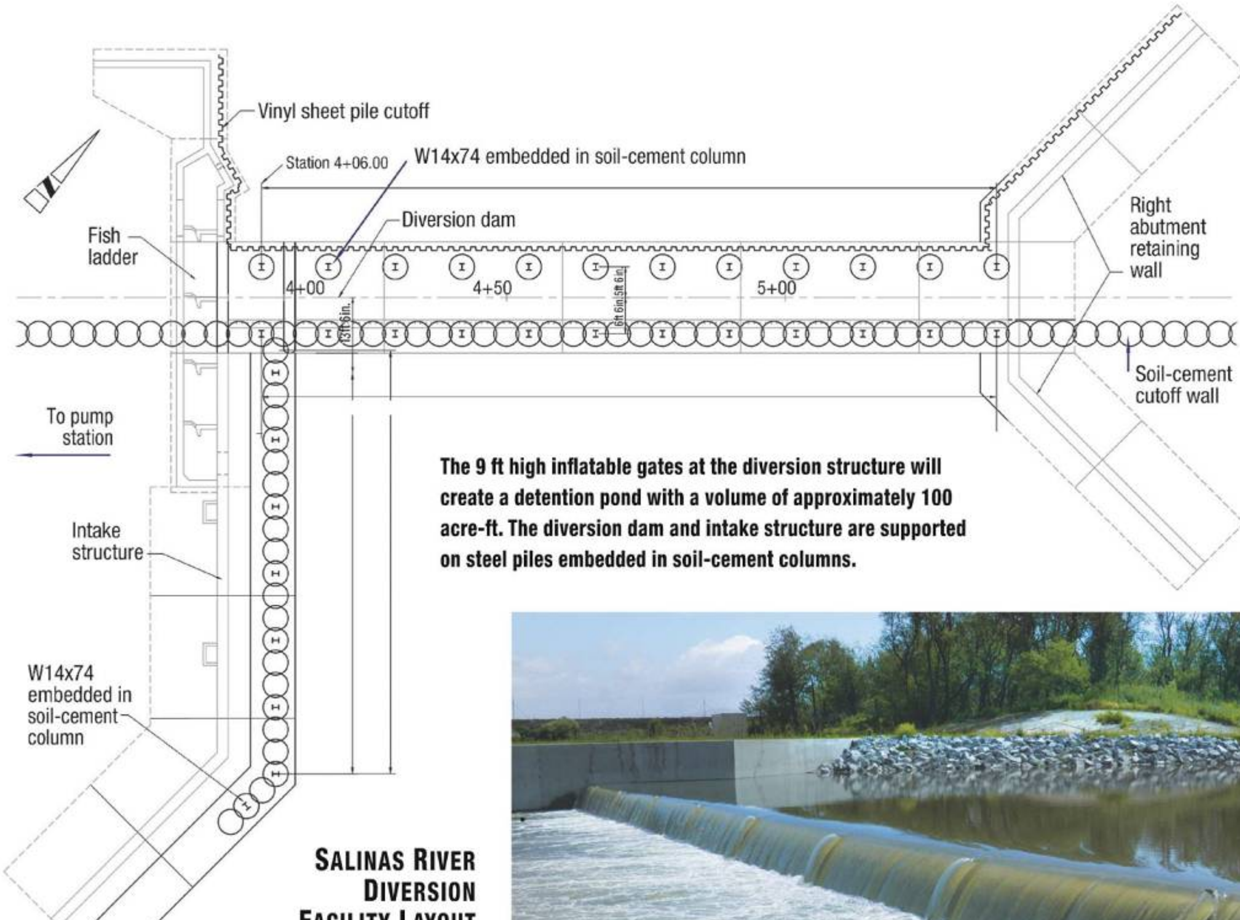


have been constructed using removable steel braces supporting wooden flashboards. Such systems can be effective and economical for dams up to perhaps 6 to 8 ft in height. However, the installation and removal process for such dams is relatively labor intensive and requires good access to the river channel. Because the SRDF project site is subject to several feet of backwater from the lagoon at the river's mouth, seasonal access to the channel area would be difficult. For this and other reasons, the MCWRA wanted to avoid the need for manual gate installation and removal. Therefore, the design team recommended a diversion dam structure equipped with remotely operated gates that could be fully lowered during the winter season and raised in the spring.

A simple and reliable system with inflatable gates manufactured by Obermeyer Hydro, Inc., of Fort Collins, Colorado, was selected for the final design. Equipped with interconnected steel panels and independent pneumatically inflatable bladders, the Obermeyer gates offer better reliability and hydraulic control than do diversion dams consisting solely of rubber bladders. Since the gate panels span the full width of the river channel, in their lowered position the flow capacity of the channel will not be significantly affected. The design includes a 128 ft wide main channel gate bay. The interconnected panels in this bay will be operated in their fully open or fully closed position. A separate 10 ft wide regulating gate bay will permit automatic adjustments as the level of the diversion pool fluctuates. Together with regulating slide gates installed at the fish ladder, the regulating gate panel of the diversion dam will make it possible to precisely control the total amount of water released downstream. This level of control is required to meet flow requirements specified in the fisheries permits.

In operation, the diversion dam structure will be subject to lateral forces from the water in the detention pond as well

URS/MCWRA, ALL ILLUSTRATIONS



SALINAS RIVER DIVERSION FACILITY LAYOUT

The 9 ft high inflatable gates at the diversion structure will create a detention pond with a volume of approximately 100 acre-ft. The diversion dam and intake structure are supported on steel piles embedded in soil-cement columns.

as to seismic lateral loads. To resist the design lateral loads and avoid excessive deformations, the foundation design required densification of loose granular soils. The design also required embedded steel piles spaced 12 ft apart on center to provide additional resistance to lateral forces (see the figure on page 75).

The SRDF intake structure had to meet particularly challenging design criteria, primarily related to fish protection. Because small fish could be present in the diversion pool, the regulatory agencies mandated the use of screens on the intake system. To protect juvenile fish from injuries associated with impingement, design criteria for typical fish screens require a minimum velocity for flows sweeping parallel to the screens and a maximum velocity for flows approaching the screens. However, in this case the diversion pool will have a very low flow velocity. As a result, the requirement for a minimum velocity for flows passing parallel to the screens could be relaxed, which in turn simplified the intake design substantially. The final design includes a series of T-shaped cylindrical drum screens mounted on a vertical headwall located just upstream of the fish ladder. Each screen unit is mounted on sliding tracks to facilitate removal and storage off-site during the winter season. The screens are equipped with automatic rotational cleaning mechanisms to prevent clogging with debris. The total screen area was designed on the basis of the approach velocity criteria for fish protection and the maximum design flow capacity of the pump station. Because the operating water levels of the diversion pool are expected to fluctuate, the intake screens were sized to maintain capacity and meet approach velocity criteria throughout the full operating range (see the figure on page 77). The selected self-cleaning drum screens, which are manufactured by Intake Screens, Inc., of Sacramento, California, are expected to perform well even with the minimal submergence expected during low pool levels.

The expected fluctuations in the level of the diversion pool of the SRDF also affected the design of the fish ladder. A ladder design with vertical slots was selected to maintain maximum functionality and consistent flows throughout the expected range of headwater and tailwater conditions. Flows into the upstream end of the ladder are regulated by two horizontally oriented submerged slide gates. At low pool levels, the lower gate will automatically open to maintain flows and control hydraulic gradients through the ladder in accordance with preset target levels. The controls for the diversion dam regulating gate are designed to be programmed and calibrated along with the controls of the fish ladder gates. In this way, the different gates will work together to ensure that total downstream flow releases remain at or above the minimum values required by the fisheries protection permits throughout the full range of fluctuating levels within the diversion pool level and normal fluctuations within the level of the tailwater.

The geotechnical design for the SRDF project was dictated by site conditions and by the seismic hazard level at the site. Geotechnical and seismic hazard investigations confirmed that the loose sandy soils present at the site would be subject to extensive liquefaction, strength loss, and large deformations during major earthquakes. To achieve satisfactory seismic performance for the proposed SRDF facilities, the design required ground improvement to mitigate the liquefaction hazard and increase resistance to seismic forces. Because of the pervious nature of the sandy soils underlying the site, the design also required measures to prevent excessive seepage and guard against internal erosion and piping. The nature of the cohesionless sandy soils in the riverbed also indicated a high susceptibility to scour erosion from high-velocity flood flows. Therefore, the project design also required extensive measures to provide protection against damaging scour and mitigate the potential consequences of its occurrence.

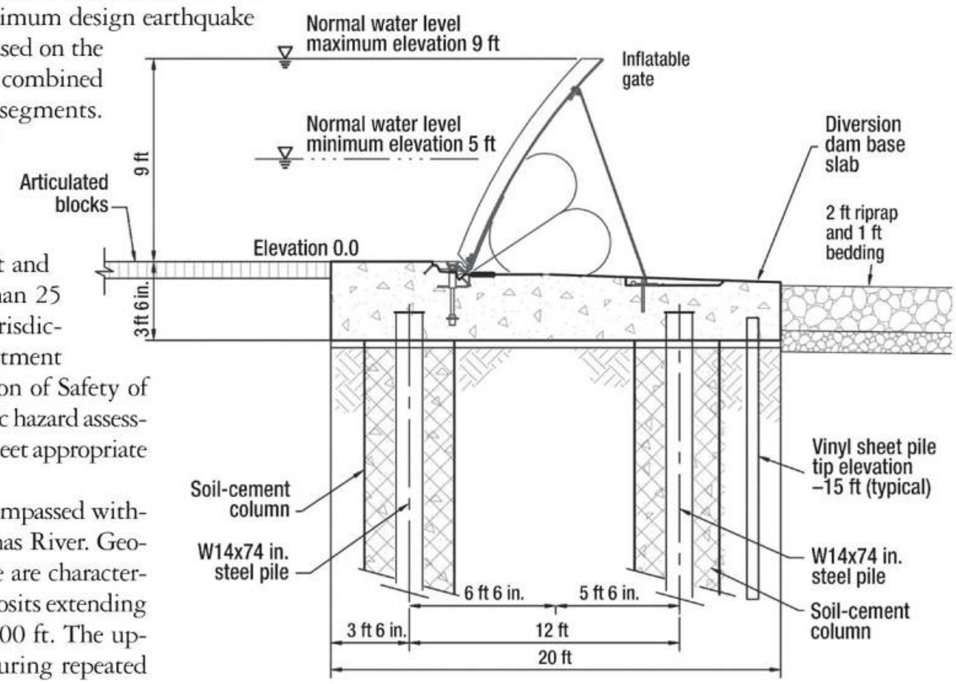
The project site is in a seismically active region of the central California coast and is influenced by several active fault zones. The San Andreas Fault is located about 15 mi from the site, and the northern end of the Reliz Fault is approximately 2.5 mi south of the site. Deterministic seismic hazard evaluations showed that the Reliz Fault controls the hazard level at the site. Although maps prepared by the U.S. Geological Survey show the Reliz Fault as discontinuous in the project area, the seismic hazard analysis for the project conservatively assumed that the fault rupture would occur as a single combined segment with the Rinconada Fault, which lines up as a southeast extension from the end of the Reliz Fault. The maximum design earthquake magnitude ($M_W = 7.0$) is based on the total 43.5 mi length of the combined Reliz and Rinconada fault segments. The resulting peak ground acceleration at the site was estimated to be about 0.65*g*. Because the diversion dam has a height in excess of 6 ft and a storage volume greater than 25 acre-ft, it falls under the jurisdiction of the California Department of Water Resources' Division of Safety of Dams. As a result, the seismic hazard assessment for the project had to meet appropriate regulatory standards.

The entire project is encompassed within the floodplain of the Salinas River. Geological conditions at the site are characterized by a complex of soil deposits extending to depths of as much as 1,000 ft. The upper deposits were created during repeated sea level fluctuations during the Pleistocene epoch, which led to two very different depositional processes: the erosion and deposition of predominantly granular alluvial and aeolian (windblown) material and the underwater deposition of predominantly fine-grained marine layers. Recent alluvial river deposits consisting of uniformly graded sands and silts are present at the surface above the older marine deposits at depth. The older soils form impermeable clayey layers separating gravelly aquifers present at depth beneath much of the northern Salinas River valley.

The existing ground surface elevations in the site area range from 15 to 25 ft above mean sea level on the riverbanks and down to about 0 to 1 ft above mean sea level in the river channel area. Extensive liquefaction and lateral spreading have been documented in the project area during major earthquakes. For example, the earthquake that struck San Francisco in 1906 caused lateral spreading damage along the Salinas River in the vicinity of the project. Liquefaction and extensive structural damage were also documented in the Moss Landing area, about 7 mi north of the site, after the Loma Prieta earthquake, which struck in 1989.

For the final design phase of the SRDF project, the site location was established on the basis of considerations pertaining to property acquisition and project layout. To characterize the geotechnical conditions along the axis of the selected site for the diversion dam, a subsurface investigation program was carried out consisting of six exploratory borings that ranged in depth from 51 to 89 ft. Four borings were drilled on the riverbanks using track-mounted equipment. Two borings were drilled in the channel area using a barge working in about 2 to 3 ft of water. The borings were all drilled using rotary wash techniques with standard penetration test (SPT) sampling in accordance with procedures set forth in

TYPICAL DIVERSION DAM SECTION



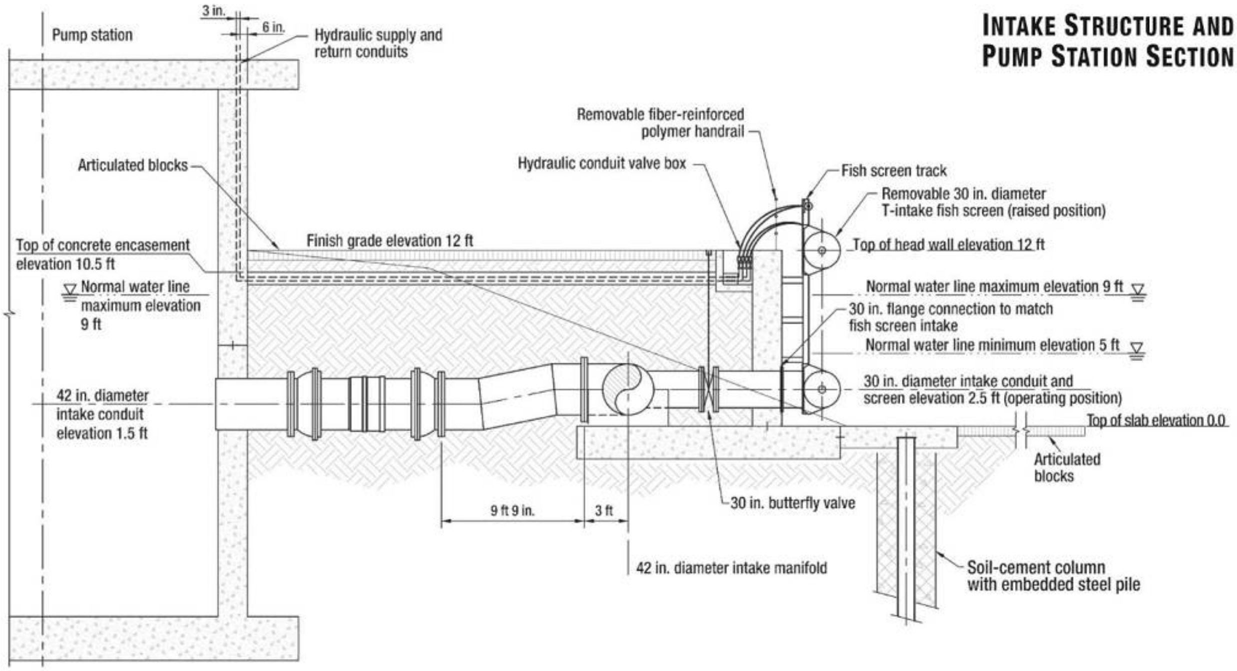
standards developed by ASTM International, of West Conshohocken, Pennsylvania. Energy measurements were taken to calibrate the SPT drive hammers and correct the blow count results. Samples were tested in a laboratory for grain size distribution, fines contents, and clay type and plasticity as part of the liquefaction susceptibility analysis. Other laboratory testing included moisture-density tests, unconfined compression strength tests, and unconfined, unconsolidated triaxial strength tests.

The figure on pages 72 and 73 depicts a simplified subsurface profile for the site showing the exploratory boring locations. The borings drilled on the south (left) riverbank encountered about 32 ft of poorly graded fine- to medium-grained sand that is loose to medium dense with occasional thin silt or clay seams. This upper sand layer generally has a fines content of 8 percent or less. The uncorrected SPT resistance ranges from 4 to 28 blows per foot but is typically less than 15. Below the upper sand, the borings encountered a layer of fine-grained alluvium that includes soft to medium stiff clayey silt and silty clay, stiff silt of low plasticity, and silty clay of medium stiffness. Below that, the borings encountered a dense, poorly graded sand layer.

The barge borings drilled in the river channel area encountered about 12 ft of very loose to loose poorly graded clean sand with an uncorrected SPT resistance ranging from 2 to 10 blows per foot. This upper sand layer was underlain by soft to stiff silty clay about 30 ft thick. Unconfined compressive strength tests and unconsolidated undrained tests on samples retrieved from this layer yielded strengths ranging from about 700 to 2,300 psf. Below this clay layer, the borings encountered a medium dense to dense silty sand layer about 10 to 13 ft thick. Below that, the borings encountered layers of very dense sand and silty sand and stiff to very stiff silty clay and silt to the maximum explored depth of 89 ft.

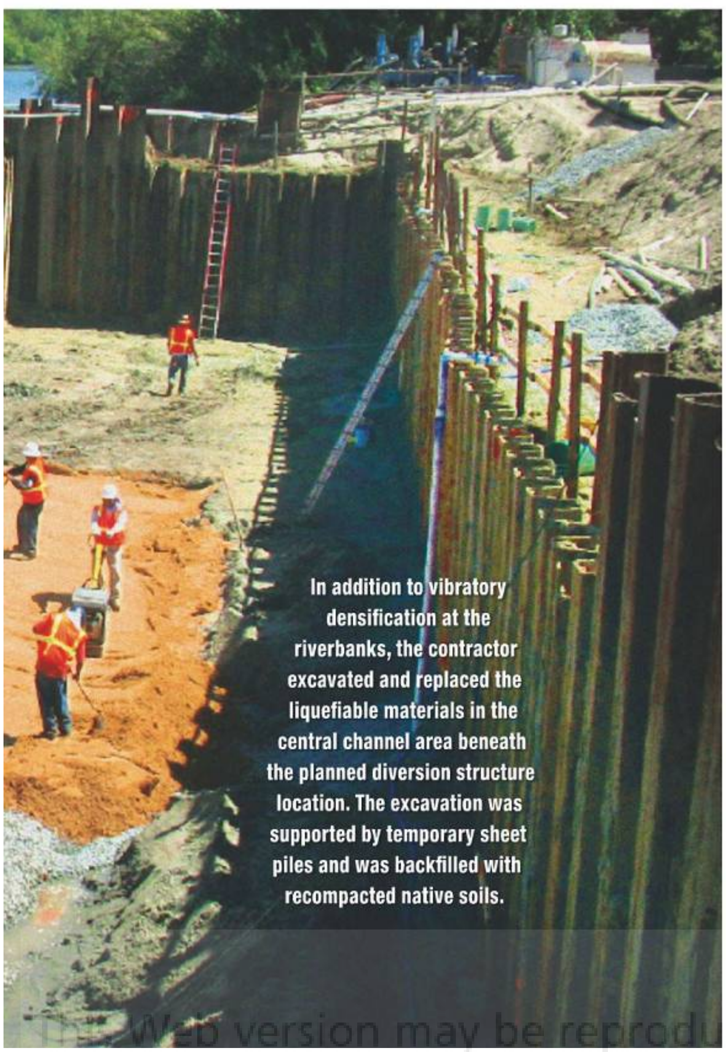
The two borings drilled on the north (right) riverbank showed a change in soil conditions from the channel to the north bank. The boring that was drilled closer to the river channel encountered an upper layer of loose to medium dense poorly graded clean sand similar to what was found in the other borings. Below the upper sand, the boring encountered high-plasticity clay of medium stiffness, as well as very dense low-plasticity silt and poorly graded clean sand down to a depth of 44 ft. Below that, the boring encountered stiff clay of high plasticity to 56.5 ft, the total depth of exploration. In contrast, the boring that was drilled at the edge of the adjacent agricultural field encountered interstratified stiff silty clays and dense sandy silts to the total exploration depth of 51.5 ft.

On the basis of the geotechnical investigation results, analyses were performed to determine the liquefaction hazard at the site for the various soil layers encountered. The analyses assessed liquefaction susceptibility, deterministic liquefaction potential, and liquefaction-induced strength loss and deformation. The liquefaction susceptibility was characterized on the basis of material type, fines content, and plasticity. The liquefaction potential was evaluated with an SPT-based deterministic triggering evaluation method that



INTAKE STRUCTURE AND PUMP STATION SECTION

compares the cyclic resistance and cyclic stress ratio for each soil layer being analyzed. On the basis of this analysis, the upper sand layer was found to have a high probability of liquefaction during the design earthquake. However, because of its greater density, liquefaction was deemed to be unlikely in the lower sand layer.



In addition to vibratory densification at the riverbanks, the contractor excavated and replaced the liquefiable materials in the central channel area beneath the planned diversion structure location. The excavation was supported by temporary sheet piles and was backfilled with recompacted native soils.

Lateral spreading is the most pervasive type of liquefaction-induced ground failure in gently sloping or waterfront ground, including the riverbanks present at the SRDF project site. During lateral spreading, blocks of relatively intact surficial soil displace downslope or toward a free face along a shear zone that forms within the liquefied soil. The amount of lateral spreading displacement that can occur depends on site topography, subsurface conditions, and the intensity of ground shaking. When a significant thickness of saturated loose soils is present, the ground surface can also settle appreciably as a result of reconsolidation of the soils that experienced liquefaction. The magnitude of liquefaction-induced ground settlement depends primarily on the subsurface stratigraphy, the soil density, and the shaking severity. Because of the distribution of liquefiable materials at the SRDF project site, the lateral spread hazard was deemed to be severe. Analyses performed for several different earthquake magnitudes indicated potential lateral spreading displacements (in unimproved ground) of up to 18 ft, consistent with observations from the 1906 earthquake.

Given the susceptibility of the selected site to liquefaction, lateral spreading, and seismically induced settlement, mitigation measures were required as part of the SRDF design. The primary design objective was to reduce the liquefaction risk and the potential for ground deformation. As part of the design studies, a number of mitigation alternatives were considered, including excavation and replacement, deep foundations, and various types of ground improvement. On the basis of the site conditions, ground improvement via densification ultimately emerged as the preferred design approach.

The ground improvement objectives were established on the basis of desired performance goals for each portion of the site. For areas directly beneath the diversion dam and appurtenant structures, the performance goal was prevention of liquefaction triggering in order to preclude excessive settlement and loss of lateral resistance. The *(Continued on Page 84)*

A Solid Foundation

(Continued from Page 77) densification criterion for these areas was initially established as a minimum corrected SPT blow count of 30 (normalized for overburden pressure and hammer energy efficiency). For riverbank areas not directly beneath project structures, the performance goal was to control ground deformation to within tolerable levels. For these areas, the densification criterion was established as an average corrected SPT blow count of 25.

The recommended area of ground improvement for the diversion dam structure included the entire width of the base slab, as well as the entire channel area extending 50 ft upstream and downstream from the edges of the base slab. At the riverbank abutments, the recommended treatment areas were designed to protect the intake and diversion structure wing walls from potential lateral spreading, with the areas extending 150 ft laterally beyond the ends of the structures. The specified depths of treatment ranged from 25 to 30 ft and extended down to an elevation 20 ft below mean sea level, corresponding to the extent of the upper sand layer.

The in situ ground improvement alternatives considered during design included deep dynamic compaction, vibratory replacement, and vibratory densification. Each method was found to have advantages and disadvantages on the basis of site conditions, treatment depths, and densification performance goals. The design team subsequently decided to specify the densification performance requirements rather than select a particular method. This gave the contractor greater flexibility in selecting a densification procedure.

Anderson Pacific Engineering Construction, Inc., of Santa Clara, California, served as the general contractor. Advanced Geosolutions, Inc. (AGI), of Santa Monica, California, which was selected as the specialty contractor for the densification work. AGI subsequently utilized both vibratory probe densification and vibratory replacement methods. The general contractor also opted to perform excavation and replacement in the central channel area beneath the diversion structure, where the liquefiable materials were shallower and excavation was more feasible.

After advertising for bids in early 2008, the MCWRA received a total of six bids, ranging from $11.0 million to $16.9 million. Because of a highly competitive bidding climate, all of the bids were below the engineer's estimate. The contract was awarded to the lowest bidder, and construction began in June 2008. The ground improvement work started in early July. AGI utilized dual vibratory probes suspended side by side from a single crane. To create the primary densification points, the probes were spaced approximately 10 ft apart on center.

After the primary densification treatment pattern was completed, verification testing was performed using a combination of SPT and cone penetration test methods. However, the initial verification test results did not meet the specified blow count criteria for portions of the treatment area. Therefore, additional coverage with a pattern of secondary and tertiary densification points was required. During the process, the cone penetration test probes confirmed the presence within the sand of thin, fine-grained seams of silt and clay, which may have impeded the densification process. Moreover, some verification test results suggested that penetration resistances continued increasing for up to five weeks after densification. Therefore, the apparent failure of some initial verification tests may have been a result of conducting the tests too soon after the densification was performed. Eventually, satisfactory in situ densification results were achieved and verified in both riverbank areas. To expedite the overall construction schedule while the riverbank densification was occurring, the general contractor decided to concurrently excavate and replace the shallower unstable soils in the central channel area. Although not without some difficulties, this too was eventually completed satisfactorily.

Once the foundation improvement work was complete, lateral support piles for the base slab of the diversion dam were installed by embedding steel wide-flange sections in the soil-cement columns. A seepage cutoff wall was installed along the dam axis and up both abutments using a slurry wall construction technique, which was a contractor-proposed modification to the originally specified deep soil mix, secant-pile cutoff wall. To protect the highly erodible soils at the site and prevent scour from undermining the structures, several protective measures were installed, including cellular concrete mats, riprap, and cutoff walls made of vinyl sheet piles.

Construction of the SRDF was successfully completed in the fall of 2009, and the project was placed into service in April of this year. The final construction cost was $13.8 million, substantially less than originally estimated. To construct the project at this very difficult site, the design had to address challenging geotechnical conditions and significant seismic hazards. Because it is located in the river, the project also had to meet complex regulatory and environmental requirements. This project represents an important milestone in the MCWRA's program to augment critical water supplies for local agriculture and to further reduce groundwater pumping and seawater intrusion into its coastal aquifers. **CE**


Feldsher

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Wu

PROJECT CREDITS

Owner: Monterey County Water Resources Agency **Prime consultant:** Boyle Engineering Corporation, Inc. (now AECOM, Fresno, California) **Geotechnical engineer and hydraulic structures designer:** URS Corporation, Oakland, California **General contractor:** Anderson Pacific Engineering Construction, Inc., Santa Clara, California **Densification contractor:** Advanced Geosolutions, Inc., Santa Monica, California