MARCH ● 2014

Civil Engineering

THE MAGAZINE OF THE AMERICAN SOCIETY OF CIVIL ENGINEERS
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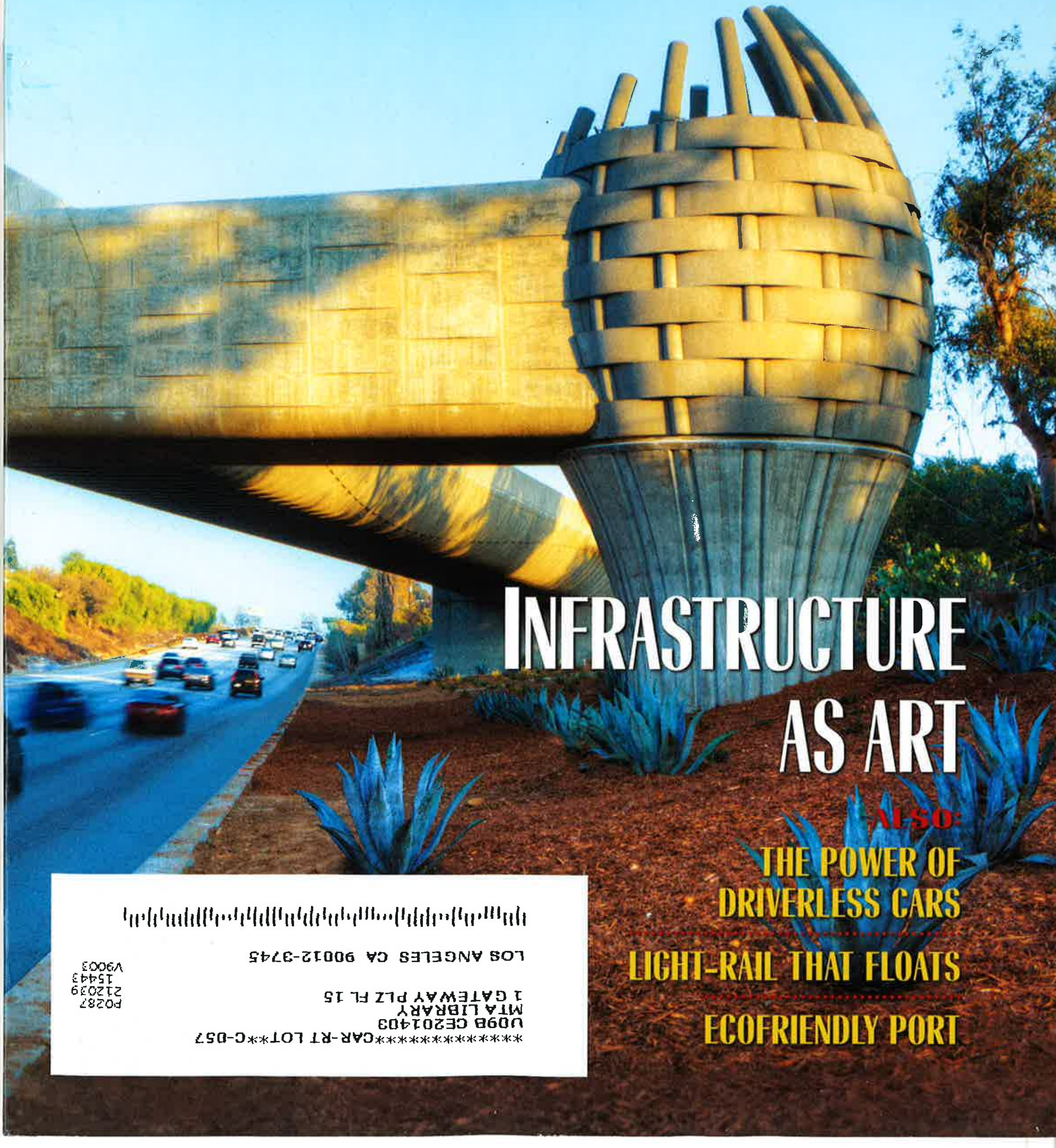


INFRASTRUCTURE AS ART

ALSO:

THE POWER OF DRIVERLESS CARS

LIGHT-RAIL THAT FLOATS

ECOFRIENDLY PORT

Golden Gateway

An iconic light-rail bridge in the valley of Southern California's San Gabriel River stands as a work of art from both an aesthetic and an engineering point of view. Located above a seismic fault, the new bridge is also a critical infrastructure element in a multiphase extension of the region's mass transit system. ••••• **By Robert L. Reid**

STRADDLING THE EASTBOUND LANES of Interstate 210 in Los Angeles County in the San Gabriel Valley is a work of public art that also serves as a bridge for the extension of the region's Gold Line light-rail system. Or is it the bridge that is also a work of art? With the Gold Line Bridge, the first mass transit crossing in California to be designed by an artist, it can be hard to tell which is more significant—the functional reinforced-concrete structure, 584 linear ft in length, that will carry light-rail trains across a major highway or the beauty of the structure's form, which features two enormous columns, one at each end of a large outrigger support beam. The columns have been designed to resemble woven baskets, and a serpentine pattern has been cast into the rounded underside of the bridge's superstructure.

Heralded as the "Gateway to the San Gabriel Valley" by the Metro Gold Line Foothill Extension Construction Authority, the government entity in charge of the light-rail extension project, the Gold Line Bridge was designed by the Minnesota-based artist Andrew Leicester. According to an illustrated brochure about the bridge produced by the construction authority entitled *Gold Line Bridge: The Art of Design,* Leicester spent nearly a year conducting research on an area

Featuring columns shaped like woven baskets, the Gold Line Bridge is the first mass transit crossing in California to be designed by an artist.

COURTESY OF THE METRO GOLD LINE FOOTHILL EXTENSION CONSTRUCTION AUTHORITY

that was once largely agricultural but is now heavily urbanized. He drew inspiration from the local architecture and the region's cultural history. As he explains in the brochure, "The large baskets that adorn the bridge metaphorically represent the indigenous people of the region and the growth of agriculture as a primary catalyst for the San Gabriel Valley's development. The baskets also pay tribute to the iconic sculptural traditions of nearby Route 66, with its oversize commercial architecture."

The $18.6-million design/build bridge project was constructed by New York City–based Skanska USA, and the Los Angeles office of the international architecture and engineering firm AECOM served as Skanska's primary design subcontractor. The superstructure of the bridge was completed late in 2012; the installation of the tracks is expected to begin this May.

The Gold Line Bridge is a key element within the nearly $2-billion Gold Line extension project, which involves the expansion of the light-rail system from its current endpoint in Pasadena to the city of Montclair, a distance of nearly 24 mi. The rail system, the Metro, is operated by the Los Angeles County Metropolitan Transportation Authority. The multiphase project includes, first, an 11.5 mi segment that is being constructed from Pasadena to the city of Azusa. (The Gold Line Bridge is located in Arcadia, near the western end of this segment.) The work during this phase includes a roughly $500-million design/build contract that was awarded to Foothill Transit Constructors, a joint venture of Kiewit Corporation, headquartered in Omaha, Nebraska, and Pasadena-based Parsons Corporation. Parsons and Kiewit both worked on the original portion of the Gold Line, from Los Angeles's Union Station to Pasadena, which opened in 2003. The Pasadena-to-Azusa extension contract involves work on nearly two dozen bridges, six new stations, the track and catenary systems, and a 24-acre maintenance and operations campus in Monrovia. Another design/build contract was awarded to San Francisco–based Webcor Builders for parking garages and intermodal enhancements at and around the new stations.

Funded by Measure R—a sales tax increase for transportation projects in Los Angeles County approved by voters in 2008—the Pasadena-to-Azusa extension reached the 50 percent completion mark in January of this year; it is expected to be completed in September 2015, at which point it will be turned over to the Los Angeles County Metropolitan Transportation Authority.

A future 12.3 mi segment with six new stations will extend the Gold Line from Azusa to Montclair. A two-year advanced conceptual engineering process is expected to begin this year and eventually lead to another design/build contract. This segment is expected to cost approximately $950 million to construct and will take approximately four years to complete, but only limited funding had been secured at press time.

The Metro Gold Line Foothill Extension Construction Authority has also studied the feasibility of extending the Gold Line from Montclair to LA/Ontario International Airport, a distance of approximately 8 mi. Although a link to the airport would not formally be part of the current extension project, the authority is continuing to study the idea as part of a "lengthy process that includes a detailed analysis of alternatives, environmental review, and preliminary engineering," its website explains.

The Pasadena-to-Azusa segment originates at the Gold Line's Sierra Madre Villa station, which is located in the median strip of I-210 because the route follows the right-of-way of the former Atchison, Topeka and Santa Fe Railway (now part of the BNSF Railway Company). Since the construction authority now owns that right-of-way, the line extension continues at grade within the median strip for 2.3 mi before crossing the southern, eastbound lanes of the freeway via the new Gold Line Bridge.

Originally designated an "iconic freeway structure," the Gold Line Bridge is a dual-track crossing that features a 220 ft main span between a single, 10 ft diameter support column, designated bent 2, located in the median strip and an approximately 113.5 ft wide, 16 ft deep posttensioned outrigger support beam, designated bent 3, that extends across the eastbound lanes. On either end of the outrigger beam stands a 25 ft tall, 17 ft diameter basket column, one in the median strip and the other located on the southern side of the freeway. Abutments at each end of the bridge feature vertically cantilevered concrete walls roughly 30 ft in height.

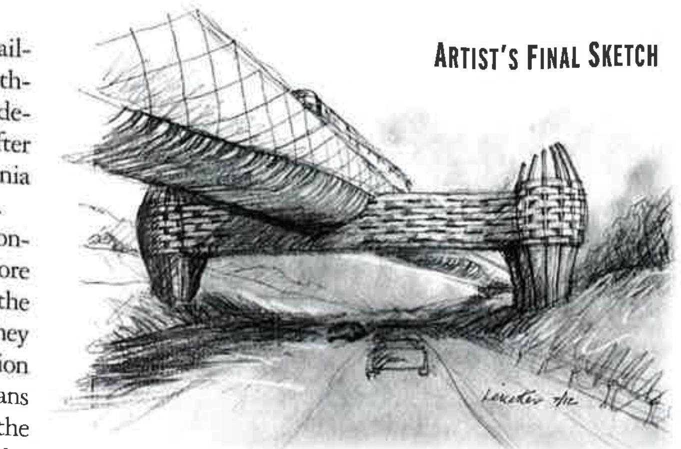
The bridge deck measures 33 ft 11 in. wide to accommodate two sets of light-rail tracks and a center emergency walkway. The vertical clearance between the freeway road surface and the bridge's rounded underside, which was cast with grooves and cuts to suggest the skin and ribs of the local diamondback rattlesnake, is 19.5 ft.

With some critical tweaks to avoid certain obstacles, the new bridge was constructed on roughly the same alignment as a single-track, precast box girder railroad bridge that crossed the freeway at the same location before being demolished in the late 1990s. The site is located within the earthquake fault zone of the Raymond Fault, says Chris Burner, P.E., M.ASCE, the construction authority's chief project officer, and the railroad bridge had been slightly damaged in 1994 by the Northridge earthquake. Because the railroad bridge was not designed to modern seismic standards, it was taken down after that earthquake as a precautionary measure by the California Department of Transportation (Caltrans), Burner explains.

Other alignments for the new light-rail bridge were considered, Burner says, but those options were deemed more complicated, more expensive, and more likely to require the purchase and demolition of surrounding homes because they would probably have been located outside of the construction authority's right-of-way. Although the new bridge also spans the fault, crossing at a 70-degree angle with respect to the fault alignment, it is a very robust structure that has been designed to withstand the possible seismic forces from the fault, Burner notes.

Acting through its project management consultant, Hill International, Inc., which has an office in Irvine, California, the Metro Gold Line Foothill Extension Construction Authority commissioned a fault study from Geo-Logic Associates, Inc., of Anaheim, California, to ensure that the new bridge could safely span the fault. The study determined the location, recurrence intervals, and possible future deformations of the fault in conformity with requirements set by the California Geological Survey and with the project goals, explains Patrick Nicholson, P.E., M.ASCE, AECOM's design manager for the project.

The geotechnical consultant examined the fault using a mix of techniques, including drilling, trenching, and a geophysical survey, Nicholson says. In particular, 72 large-diameter (24 to 30 in.) borings were drilled to depths of as much as 104 ft below grade. As Burner explains, "They actually lowered geologists in baskets into these shafts, and they went down and mapped the strata of the soil." Two borings with smaller diameters also were drilled, and a fault trench roughly 170 ft long and 14 ft deep was excavated for additional field observations of the soil strata, Nicholson says. Use was also made of refraction microtremor technology, which is not sensitive to nearby traffic or other electromagnetic noise, to develop geological data across the fault zone.

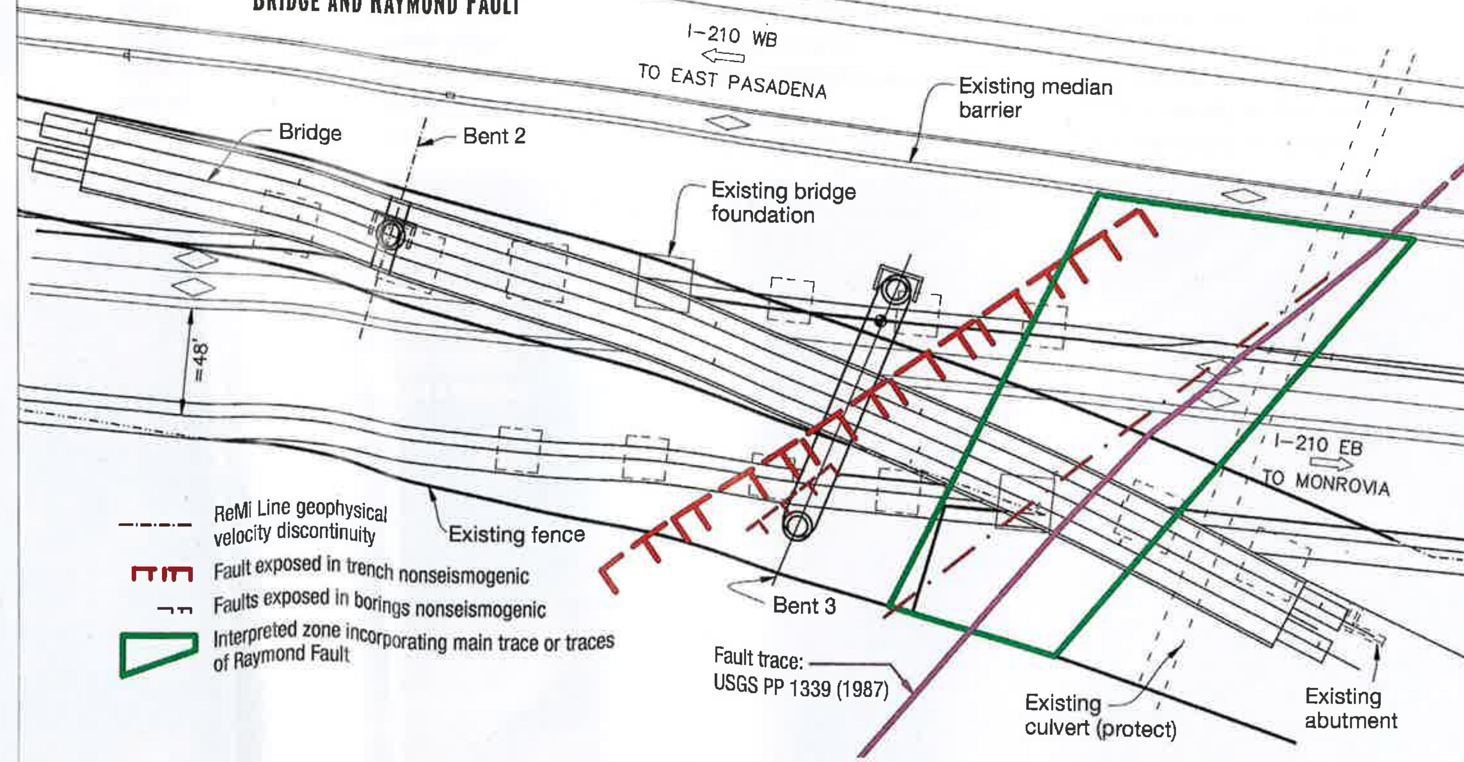


ARTIST'S FINAL SKETCH

As a result of the fault study, an "interpreted fault zone" approximately 140 ft wide by 210 ft long was established at the bridge site that encompassed the traces of the main fault and associated secondary faults. The bridge foundations were carefully designed so that they would be at least 50 ft away from the interpreted zone while also accommodating such other considerations as optimal bridge layout and right-of-way limitations, explains Nicholson.

Large-diameter piles cast in drilled holes were selected for the support columns to minimize the foundation footprint. These 110 ft deep, 11 ft diameter piles also proved to be crucial to the seismic response of the structure and to mitigating the potential for soil liquefaction, Nicholson notes. The test borings had revealed that the groundwater level was more than 70 ft below grade. Given the drying trend and

BRIDGE AND RAYMOND FAULT



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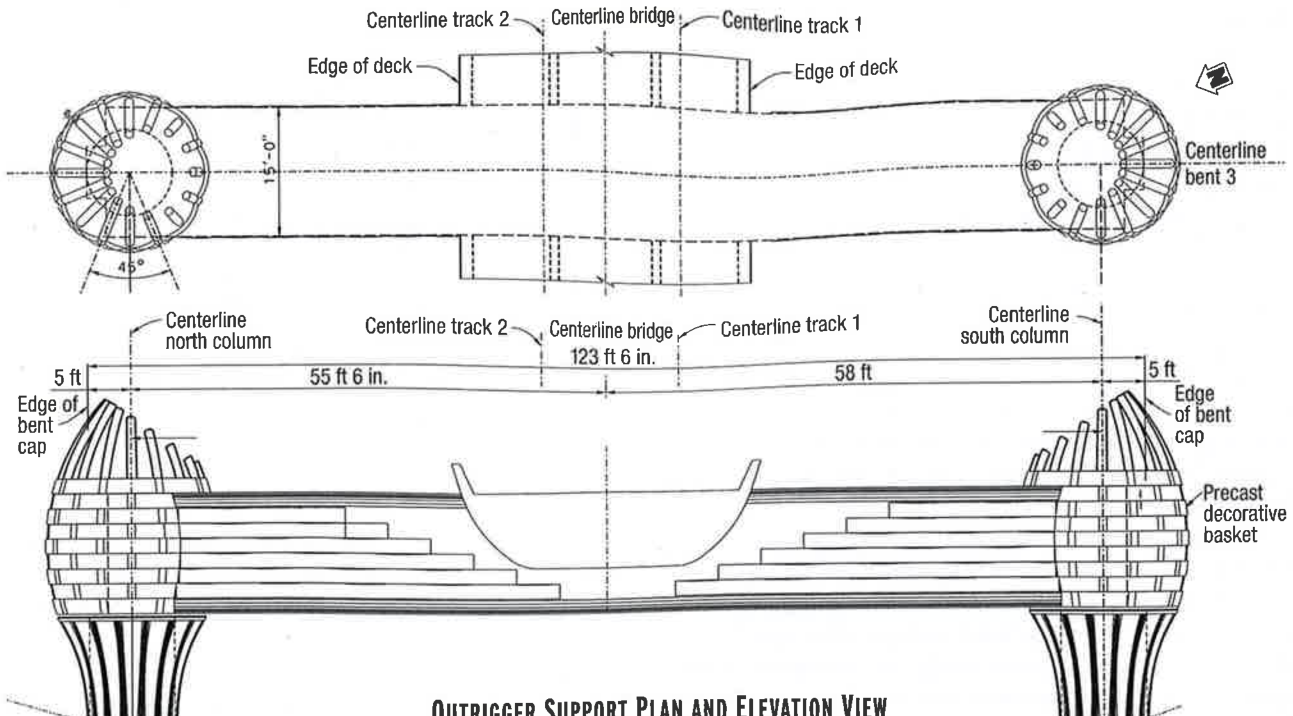


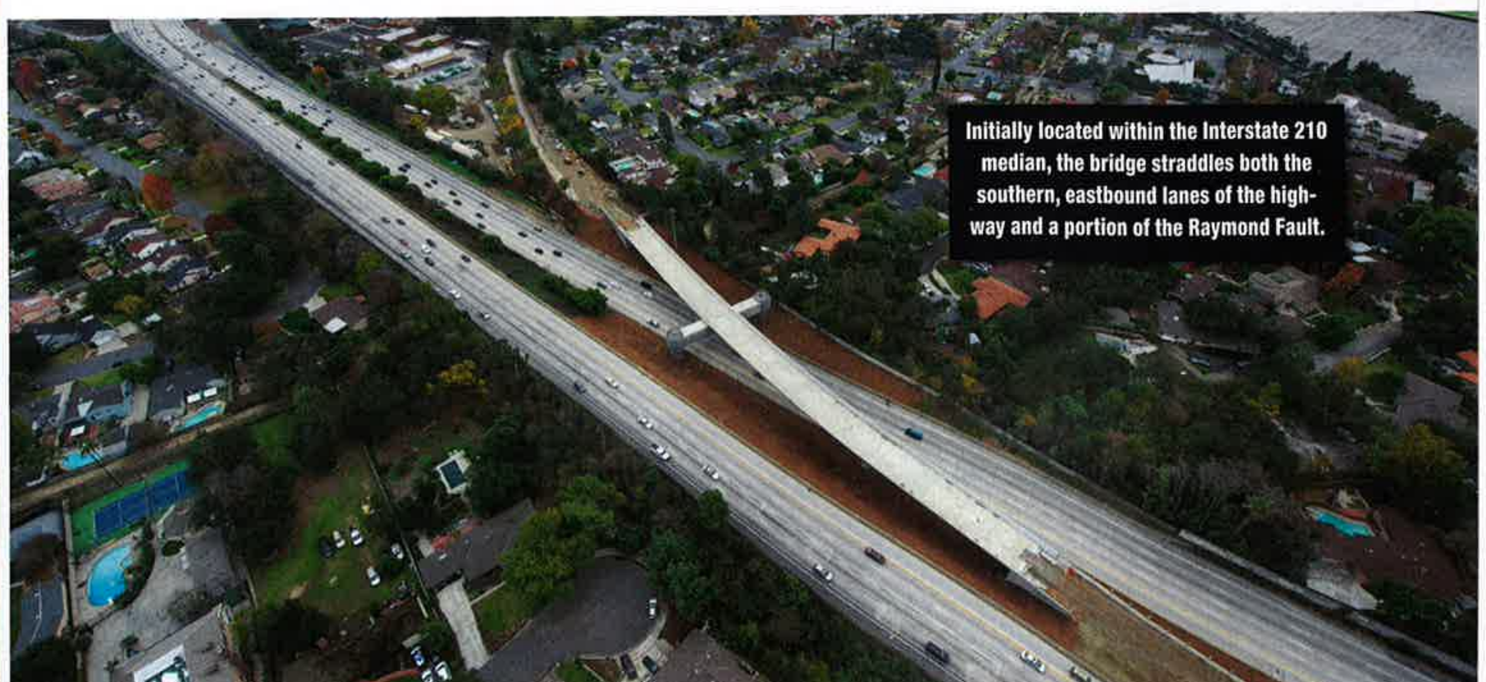
OUTRIGGER SUPPORT PLAN AND ELEVATION VIEW

population hike of Southern California in recent decades, the geotechnical consultant had originally proposed 80 ft deep piles to accommodate a groundwater level of 50 ft below grade. However, the historical data indicated that groundwater had reached 10 ft below grade in 1968, which concerned some of the project's stakeholders, Nicholson relates. Considerations of safety, economy, design, and constructability led to numerous discussions by various parties, he explains. Eventually the design featured a practical yet conservative estimate of 20 ft below grade for groundwater but ignored the end-bearing capacity of the piles, he concludes.

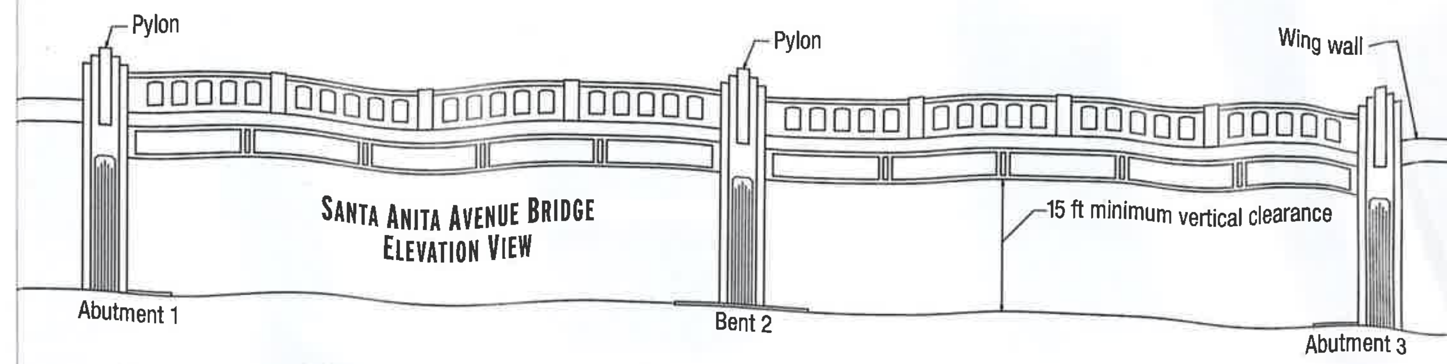
Piles 2 ft in diameter cast in drilled holes formed the foundations of the abutments.

Because the new bridge was being constructed on the site of the original railroad bridge, the design initially called for the removal of the demolished bridge's piles. These driven precast piles were approximately 20 ft deep or so, says Nicholson. "We thought we could extract those piles—use a big vibrator to pull them out," he explains. But since the extraction efforts failed, the layout of the new piles had to be reconfigured and the bridge had to span the old foundations, he notes. In fact, the old piles were just one of many belowground and aboveground obstacles. The impediments also included utilities, a storm drain channel, and large power poles, forcing the design/build team "to really thread the needle through all of that" to determine the exact, final alignment, Nicholson says.

The fault study also recommended that the bridge be able to accommodate a 0.5 m horizontal surface fault rupture.



Initially located within the Interstate 210 median, the bridge straddles both the southern, eastbound lanes of the highway and a portion of the Raymond Fault.



SANTA ANITA AVENUE BRIDGE ELEVATION VIEW

Although conventional wisdom calls for avoiding any such surface fault rupture zones, this was not an option for the Gold Line alignment, Nicholson says. Fortunately, Caltrans at that time was finalizing a multiyear research project to determine the design issues pertinent to this problem. While past design methodologies had focused only on the static displacement induced by a surface fault, the new criteria proposed on the basis of Caltrans's research recognized both the static and the dynamic nature of a surface fault and included practical analysis procedures for the designer to follow, Nicholson explains. Because the Gold Line Bridge was the first project to implement these new criteria, intensive brainstorming sessions involving representatives of Caltrans, the Metro Gold Line Foothill Extension Construction Authority, the design/build team (Foothill Transit Constructors), and Metro were conducted throughout the design, he notes.

The fact that the I-210 freeway would pass directly beneath the Gold Line Bridge meant that the design had to accommodate the desire by Caltrans for a structure that would be more ductile and thus experience greater displacement during a seismic event, notes Nicholson. At the same time, Metro sought a structure with greater elasticity so that any damage to the piled shafts from an earthquake would be more repairable, he adds. To accommodate the contradictory preferences, AECOM's specialty practice group proposed the use of a ductile shaft for the bridge columns combined with time-domain reflectometry technology that during a seismic event would detect the formation of plastic hinges in a shaft, an indication of underground damage. The result was the creation of a so-called smart shaft, the first use of this approach in California bridges, Nicholson explains.

Widely used in geotechnical applications to monitor ground movement, time-domain reflectometry utilizes fiber-optic cables and a signal generator that emits electric pulses, Nicholson explains. In the Gold Line Bridge, four equally spaced cables were embedded just inside the perimeter of each column shaft, the upper ends terminating in a monitoring station, Nicholson notes. If a plastic hinge forms, the cable or cables will be crimped or stretched, generating a detectable "reflection" that will reveal the location of the hinge. In this way troubleshooters will be able to demarcate the damaged area, Nicholson says. The resulting smart shaft both enhances the seismic performance of the structure and makes it easier to locate underground damage, he concludes.

Geologists were lowered in baskets to depths reaching 104 ft deep in shafts to map the soil strata.

Leicester's sculptural design of the Gold Line Bridge was described as an opportunity to "think outside the box girder," according to Habib Balian, the Metro Gold Line Foothill Extension Construction Authority's chief executive officer, writing in *Gold Line Bridge: The Art of Design*. But one aspect of the structure's signature look and form was almost nixed by Caltrans. The undersides of highway bridges in California had always been flat prior to the Gold Line Bridge, says Nicholson. So Caltrans was initially reluctant to approve the rounded design that featured the deep grooves and cuts that suggest the skin and skeleton of a snake. "[I]t took a lot of back and forth to work through the agency's concerns. In the end, Caltrans allowed it," explained Rivka Night, AECOM's principal architect on the project, writing in *Gold Line Bridge: The Art of Design*. Night, whose responsibility was to translate Leicester's vision into a buildable structure, also praised Skanska USA's efforts to accommodate the "unusual design."

Not all aspects of Leicester's vision made it into the finished structure, though. Originally the artist had designed two sets of outrigger supports and baskets for a longer bridge, notes Nicholson. But since a shorter bridge would better accommodate the span over the Raymond Fault, Nicholson says, one of the outriggers was eliminated. Furthermore, the basket design, which features a series of simulated reeds rising vertically above the horizontal woven pattern, had originally called for taller, thinner reeds. But those proved difficult to construct, noted Night, and so shorter, thicker reeds ended up in the final version.

The baskets were also challenging because of the variety of shapes involved and the different solutions that had to be considered, Nicholson says. The first idea was to cast the basket columns in place when the outrigger beam was cast, but that idea was rejected when it was decided to posttension the outrigger beam. Thus, it became *(Continued on Page 75)*

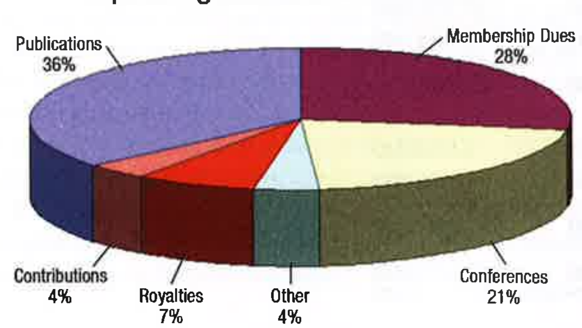
As the national economy slowly recovers, we have continued to carefully manage our resources and pursue our strategic initiatives to strengthen the profession and better serve society.

AMERICAN SOCIETY OF CIVIL ENGINEERS AND AFFILIATES CONSOLIDATED STATEMENT OF ACTIVITIES

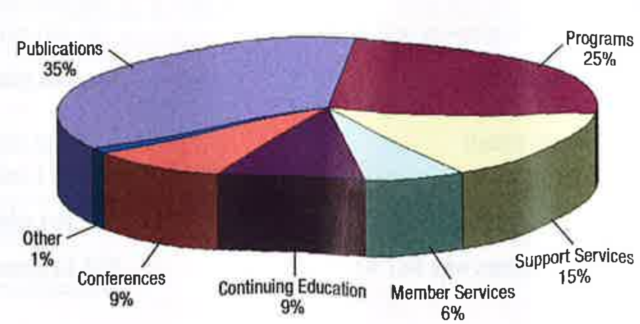
For the Year Ended September 30

	2013	2012
OPERATING REVENUE		
Membership dues	$15,245,000	$14,799,000
Publication sales	17,431,000	16,791,000
Conferences and seminars	11,108,000	10,076,000
Advertising	2,215,000	2,114,000
Royalties	3,588,000	4,095,000
Contributions	1,920,000	1,460,000
Rental income	582,000	597,000
Operating investment earnings	1,235,000	2,049,000
Other income	605,000	923,000
Total Operating Revenue	**53,929,000**	**52,904,000**
OPERATING EXPENSE		
Program Services:		
Program activities	18,897,000	19,139,000
Publications and advertising	14,038,000	11,986,000
Continuing education	4,906,000	5,454,000
Customer and member services	3,141,000	3,063,000
Conferences	4,930,000	4,271,000
Other	386,000	438,000
Total Program Services	46,298,000	44,351,000
Support Services:		
General and administrative	3,715,000	4,147,000
Membership and marketing	3,311,000	3,731,000
Fund raising	1,024,000	632,000
Total Support Services	8,050,000	8,510,000
Total Operating Expenses	**54,348,000**	**52,861,00**
(Deficit) Excess of Operating Revenue over Operating Expense	**(419,000)**	**43,000**
NONOPERATING REVENUE		
Long-term investment earnings	4,092,000	4,194,000
INCREASE IN NET ASSETS	**$3,673,000**	**$4,237,000**

Operating Revenue — Fiscal 2013



Operating Expense — Fiscal 2013



Golden Gateway

(*Continued from Page 51*) necessary to have access to the two ends of the beam, Nicholson notes. Precast panels also were considered and rejected because Caltrans was concerned about the difficulty of conducting inspections for corrosion on difficult-to-access plates. In the end the design/build team decided on a masonry design in which each element of the basket would be molded and cast separately, with cast-in-place dowels on the back side. The individual pieces would then all be mortared together so that the entire bridge would behave as a single unit, Nicholson explains.

Always intended as a landmark structure, the Gold Line Bridge has been the recipient of a number of engineering and construction awards, including the 2013 Engineering Achievement Award from the American Council of Engineering Companies' Los Angeles County chapter and the 2013 Project Achievement Award from the Construction Management Association of America. The Metropolitan Los Angeles Branch of ASCE's Los Angeles Section honored the structure with its Outstanding Public Civil Engineering Project Award in the category of transportation projects costing more than $10 million.

Although the Gold Line extension from Pasadena to Azusa is being constructed along a former freight railroad right-of-way, that railroad will still be operating in close proximity to at least a portion of the new line. As part of Foothill Transit Constructors' work, approximately 3.5 mi of the railroad's track at the eastern end of the 11.5 mi light-rail extension is being relocated and reconstructed approximately 30 ft to the south, explains David Warnock, P.E., M.ASCE, a Parsons design manager. BNSF will continue to serve two customers along that 3.5 mi segment, its new tracks separated by a fence from the new tracks of the light-rail extension, Warnock explains.

Other features of Foothill Transit Constructors' contract include the renovation or replacement of approximately two dozen bridges along the route, as well as the construction of a bridge to replace a grade crossing on a major highway. At the San Gabriel River, for example, a single-track railroad bridge was demolished, and a new, 700 ft long, double-track crossing is being constructed in its place. But because the river is part of a major flood control channel and is under the jurisdiction of both the U.S. Army Corps of Engineers and Los Angeles County, work at the site was restricted to an April 15 to October 15 time frame, Warnock notes. Moreover, the new bridge will be at an elevation at least 2 ft higher than the previous structure to provide proper clearance in the event of a 98,000 cfs flood event.

At Santa Anita Avenue, considered the entrance to the city of Arcadia and a primary access route to Santa Anita Park, a well-known horse racing venue, the city itself funded a grade separation project, Warnock says. The hump in the road that had previously enabled vehicles in the intersection to drive over the railroad tracks, which were at a slightly higher elevation than the surrounding grade, was demolished. The surrounding road was then lowered by approximately 4 ft, and elevated approach spans and an attractive light-rail bridge with decorative pylons and railings are being constructed above the former grade crossing, Warnock says.

An even more dramatic grade change is in the works at the site of the planned 24-acre maintenance and operations facility, which is being constructed in Monrovia, just north of the new light-rail tracks. Here, there was a roughly 15 to 17 ft difference in grade between the land adjacent to the light-rail route and the land just to the north, Warnock says. To accommodate the light-rail trains that will use the facility for service, cleaning, and other purposes, the site had to be leveled by excavating soil from the north end and then using that soil in compacted lifts to build up the elevation at the south end. Roughly two thirds of the site was lowered, while one third was raised, Warnock estimates. A roughly 700 ft long concrete retaining wall was constructed at the north end of the site to support a road that runs along the excavated area.

The main structure at the facility will be the 125,000 sq ft shop building, at which light-rail trains will be inspected and maintained; this building will also feature offices, training rooms, and an observation tower so that operators can observe the yard and send trains to the correct tracks, Warnock explains. There will also be a building for maintenance-of-way vehicles and equipment, an automated "car wash" building for cleaning the exteriors of the trains, and a covered cleaning platform roughly 300 ft long from which cleaning crews will be able to access the interiors.


Reid

With sustainability in mind, which encompassed, among other features, the use of natural lighting and ventilation, the reuse of building materials, and the expected reductions in water consumption, the maintenance and operations facility is being designed to achieve silver certification in the U.S. Green Building Council's Leadership in Energy and Environmental Design (LEED) rating system, Warnock notes. If successful, it would be one of the first such facilities in California to meet that standard and would definitely become a standout portion of a landmark project that is focused on both aesthetics and performance. **CE**

Robert L. Reid is the senior editor of Civil Engineering.

PROJECT CREDITS Owner: Metro Gold Line Foothill Extension Construction Authority, Monrovia, California **Gold Line Bridge designer:** Andrew Leicester, Minneapolis **Gold Line Bridge design/build contractor:** Skanska USA, New York City **Gold Line Bridge lead architect and design engineer:** AECOM, Los Angeles office **Gold Line Bridge project management consultant:** Hill International, Inc., Irvine, California **Gold Line Bridge geotechnical engineer of record:** Group Delta Consultants, Inc., Torrance, California **Gold Line Bridge geotechnical consultant:** Geo-Logic Associates, Inc., Anaheim, California **Pasadena-to-Azusa extension design/build contractor:** Foothill Transit Constructors, a joint venture of Kiewit Corporation, Omaha, Nebraska, and Parsons Corporation, Pasadena, California **Pasadena-to-Azusa extension design/build contractor, parking garages and intermodal enhancements:** Webcor Builders, San Francisco