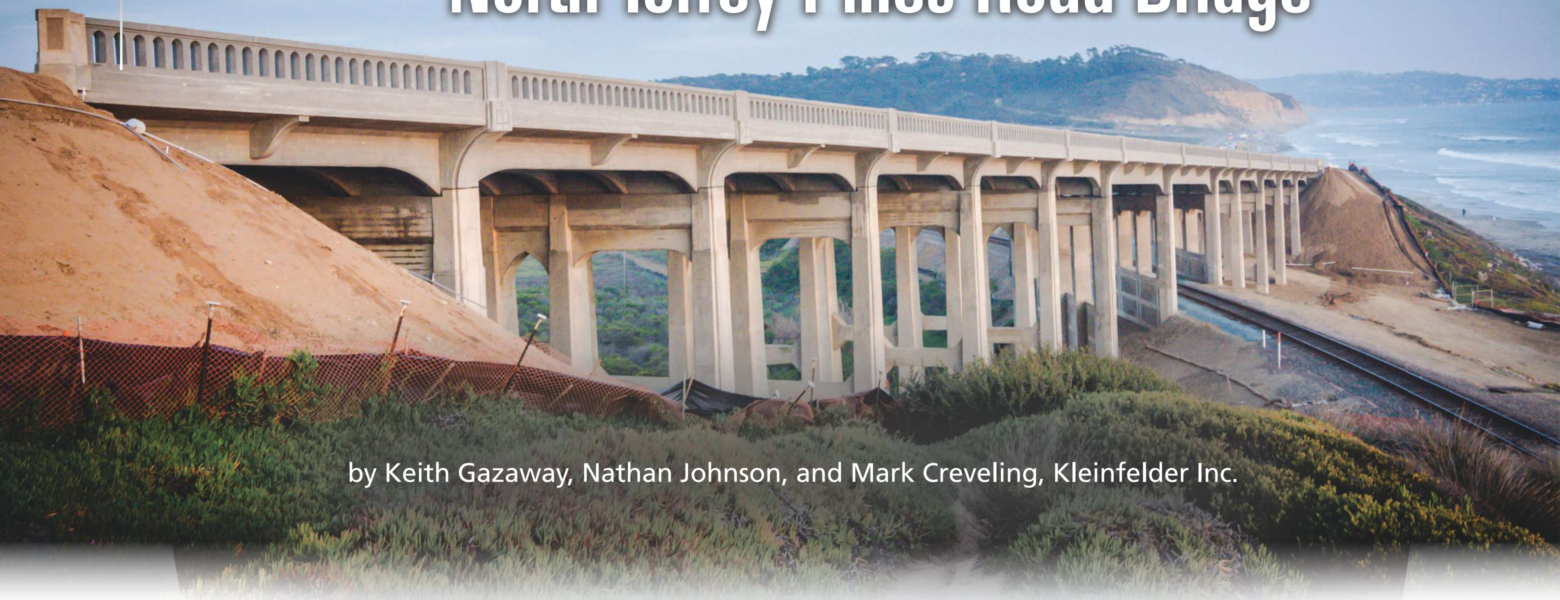
PROJECT

Rehabilitation and Seismic Retrofit of the North Torrey Pines Road Bridge



by Keith Gazaway, Nathan Johnson, and Mark Creveling, Kleinfelder Inc.

Bridge after construction. All Photos and Figures: Kleinfelder Inc.

Situated along the scenic coastline at the northern border of San Diego, Calif., the North Torrey Pines Road Bridge is a landmark structure valued by the local community of Del Mar for its historical significance and aesthetic appeal. Until recently, the iconic structure was slowly succumbing to corrosion and was highly susceptible to seismic damage. In 2000, the city of Del Mar bought the bridge for $1 from the city of San Diego when the two cities could not agree on whether to repair or replace the bridge. Now, the city of Del Mar, with help from the Federal Highway Administration (FHWA) and local transportation funding sources, has infused this 83-year-old landmark with new life and strength to maintain its beauty for at least 50 more years. It will remain one of the more significant historic examples of cast-in-place concrete bridges on the coast of California.

Apparent Deficiencies

The original 550-ft-long bridge superstructure consisted of 15 simply supported T beam concrete girder spans on multi-column bents ranging in height from 30 to 70 ft. Most of the bents are normal to the roadway, but where the bridge crosses over the active railroad at a 63-degree skew, complex geometry requires several bents to be conjoined, resulting in a stiff network of columns and railroad collision walls.

In the early 1990s, the California Department of Transportation (Caltrans) added the bridge to the statewide federally mandated seismic retrofit program, and subsequently identified it as structurally and seismically deficient and functionally obsolete. As of 2008 it had a bridge sufficiency rating of 19 out of 100, which was mostly attributed to severe and extensive corrosion throughout the superstructure and substructure due to the coastal environment.

Suffering from Corrosion

Although much corrosion damage was plainly visible, an exhaustive investigation and materials evaluation of the bridge was warranted including delamination surveys, material sampling and testing, nondestructive and destructive testing, and continuity testing. Corrosion of the superstructure

profile

NORTH TORREY PINES ROAD BRIDGE / DEL MAR, CALIFORNIA

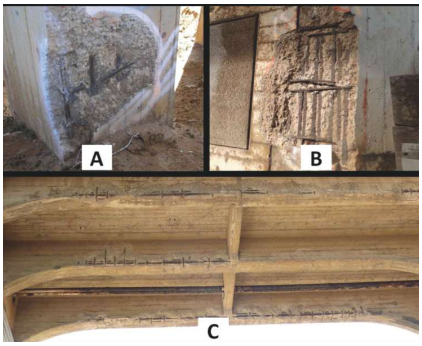
BRIDGE DESIGN AND GEOTECHNICAL ENGINEER: Kleinfelder Inc., San Diego, Calif.

CONSTRUCTION MANAGER: T. Y. Lin International, San Diego, Calif.

PRIME CONTRACTOR: Flatiron West, San Marcos, Calif.

PRECASTER: Oldcastle Precast, Perris, Calif.—a PCI-certified producer

POST-TENSIONING CONTRACTOR: DYWIDAG-Systems International USA, Long Beach, Calif.



Corrosion on (a) column, (b) railroad collision wall, and (c) underside of girders.

was so severe that it was eventually agreed the best solution was to replace all of the girders.

Substructure corrosion was also extensive, although less severe than that of the superstructure. Cracked and delaminated concrete covered one-third of the substructure surface. The main source of corrosion was chloride intrusion, which is typical in a marine environment. Fortunately—despite the pervasive concrete damage due to corrosion throughout the substructure—most of the primary longitudinal reinforcement suffered minimal section loss even after 83 years in service in the marine environment and was able to be reused in the columns.

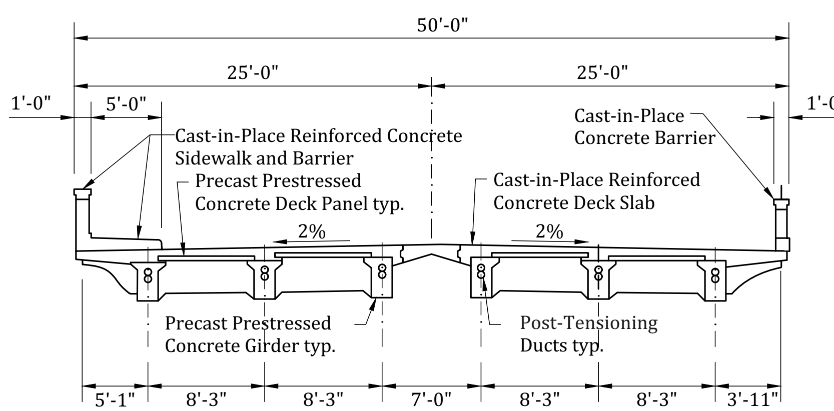
At Risk from Earthquakes

From 1999 through 2008, engineers performed several linear frequency domain analyses for the as-built bridge. All studies arrived at the conclusion that the bridge had several seismic vulnerabilities. As the retrofit studies progressed, and the scope began to focus on seismic retrofit rather than replacement, analytical methods became appropriately more refined.

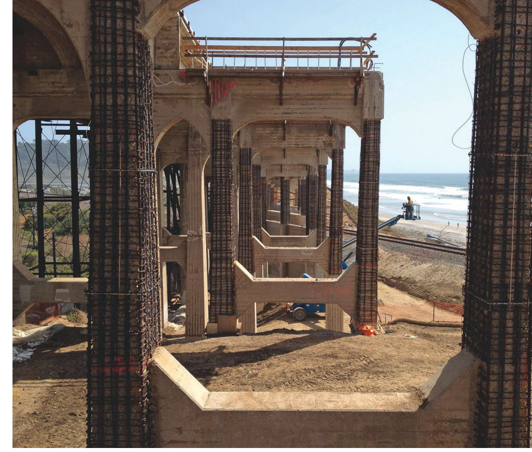
Teams of structural and geotechnical engineers performed thorough seismic analyses using state-of-the-art methods including nonlinear pushover and time history analyses.

Geological layering beneath the bridge was highly variable. Therefore, to complete the seismic analysis, the bridge was broken into five geographic zones, each having a slightly different ground motion during the multiple-support nonlinear time history analysis. This investigation revealed several issues that would present safety risks during a major earthquake:

- Multiple lenses in soil beneath the structure with high potential for liquefaction
- Southern abutment susceptible to lateral spreading, possibly leading to bridge collapse
- Shear deficiencies in all columns and abutments
- Seat widths insufficient to prevent unseating of spans
- Large substructure displacements exceeding flexural ductility capacity
- Conjoined skew bents attracting seismic demands in excess of shear capacities of caps, columns, and joints



Typical section of new post-tensioned precast, prestressed concrete superstructure.



Installed column ties after removal of cover concrete.

Community Concept

The city of Del Mar conducted a study to compare a bridge replacement option (considering a variety of structure types) with retrofit and rehabilitation. The study indicated that it would cost slightly more to retrofit the bridge and extend its life by 50 years than to replace the bridge using new design standards. After extensive stakeholder meetings and public input, the consensus from the community was a strong desire to retrofit the much-loved, historic bridge despite the additional cost. During the environmental phase of the project, the city approved a plan to retrofit the bridge and preserve the

CITY OF DEL MAR, OWNER

BRIDGE DESCRIPTION: A 15-span, 550-ft-long, 50-ft-wide, cast-in-place reinforced concrete T-girder bridge, rehabilitated using a post-tensioned superstructure, consisting of precast, prestressed concrete girders, that replicates the previous structure.

STRUCTURAL COMPONENTS: 80 custom haunched precast, prestressed concrete girders varying in length from 15 to 57 ft; 282 precast, prestressed concrete deck panels with a 5-in.-thick cast-in-place deck; and repaired concrete columns

PROJECT CONSTRUCTION COST: $21 million

AWARDS: "Outstanding Environmental Solution," AEP San Diego, 2009; "Best Available Environmental Technology Award," NAEP, 2010; "Outstanding Project, Bridge," ASCE San Diego, 2013; "Project of the Year," APWA San Diego Imperial County, 2014; "Award of Excellence, Transportation $5-15M," CMAA San Diego, 2014; "Top 10 Bridges Award," *Roads & Bridges* magazine, 2014; "Outstanding Historical Renovation Project," ASCE Region 9, 2014; "Transportation Award," ACI San Diego, 2014; "Honor Award," ACEC California, 2015; "PCI Design Award, Best Rehabilitated Bridge," PCI, 2015; "California Best Project, Highway/Bridge," *ENR* California, 2015

Temporary bridge widening adjacent to environmentally sensitive area.

bridge's eligibility for listing on the National Register of Historic Places.

The city of Del Mar and its stakeholders stipulated that the railway corridor beneath the bridge, and the bridge itself, remain open to train, vehicle, pedestrian, and bicycle traffic during construction. Additionally, the construction work could not harm sensitive coastal habitat or species beneath the bridge.

The design team that performed the as-built condition evaluation and alternative analysis was also tasked with environmental and regulatory permitting, final design, and construction support. Due to the project complexity and high-profile designation, an esteemed peer-review team of experts was contracted to review the alternative selection and design.

Retrofit and Rehabilitation Strategy

The North Torrey Pines Road Bridge retrofit design criteria pushed well beyond typical structural and geotechnical methodology used for seismic design and retrofit of California bridges. A matrix was created to compare retrofit alternatives with project constraints. Several conventional and nonconventional retrofit methods were compared, including traditional substructure strengthening, complete isolation, and partial isolation with stiffness redistribution from select substructure elements. The selected retrofit and rehabilitation solution, while addressing environmental, historic, and usage constraints, was a unique concert of performance-based geotechnical and structural engineering design.

Pacific Ocean in front of bridge during superstructure demolition.

The major elements of the rehabilitation and retrofit strategy included

- soil densification using compaction grouting to mitigate liquefaction and lateral spreading;
- strengthening columns by removing cover concrete, adding shear reinforcement, and replacing concrete to its original dimensions;
- partial superstructure isolation with sliding bearings to protect stiff skewed bents;
- new deep foundation abutments to help restrain the partially isolated superstructure;
- end-to-end post-tensioning of the precast concrete superstructure to transmit lateral seismic force to select bents and the new abutments; and
- a corrosion protection plan using cathodic protection for elements that will remain in place.

Precast concrete girders were selected to maintain the railroad's required clearance envelope during construction. The precaster built multiple custom forms to replicate the existing girder dimensions, including end haunches, skews, and surface texture, and the precaster also created a three-dimensional virtual model of each girder to ensure the reinforcement and prestressing would fit perfectly within the forms.

Prior to post-tensioning, the pretensioned concrete girders were capable of carrying AASHTO HL-93 live loading; however, post-tensioning the girders provided continuity for lateral seismic loads and also increased the girders' vertical capacity to carry the weight of California's permit vehicles. While a cathodic protection system will protect the substructure elements, the partially isolated superstructure relies on epoxy-coated reinforcing steel, increased concrete cover, limited water-cement ratios, and concrete admixtures to resist chloride penetration and reinforcement corrosion.

Construction Stages

The retrofit of the North Torrey Pines Road Bridge began in December 2010. Since the bridge crosses over the second-busiest passenger rail corridor in the United States, construction crews had to work around schedules for passenger rail, commuter rail, and freight rail users. Items such as demolition, which required temporary closure of the rail corridor, needed to work around strictly scheduled weekend closure windows.

Pedestrian, bicycle, and vehicular traffic needed to be maintained during the approximate 2-year duration of construction. Therefore, the bridge was constructed in two phases, where traffic was shifted to one side, half was demolished and rehabilitated/retrofit; then traffic was shifted to the new portion, and the other side was demolished and rehabilitated/retrofit.

To allow for the two-lane bridge to remain open to two lanes during construction, the engineering and construction teams developed a temporary steel bridge structure that could be placed on one side of the bridge and moved to the other side in a subsequent stage. The temporary structure was braced laterally against the seismically deficient bridge, which required extensive analysis to ensure safety during construction.

The North Torrey Pines Road Bridge retrofit was completed by December 2013 on time, on budget, and to the satisfaction of the city of Del Mar, its stakeholders, and the community. The bridge is now stabilized against corrosion, structurally and seismically sound per the current bridge standards, and—most important—preserved with its historic character for future generations.

Keith Gazaway is a principal bridge engineer, Nathan Johnson is director of bridge engineering, and Mark Creveling is senior vice president of transportation for Kleinfelder Inc. in San Diego, Calif.

Precast concrete girders erected on rehabilitated substructure.

AESTHETICS COMMENTARY

by Frederick Gottemoeller

The North Torrey Pines Bridge is typical of its era, a time when owners were willing to build aesthetic details like recessed column corners and haunched T girders into their bridges in order to give them an aesthetic "personality" suitable for their locations, in this case along a beautiful seashore. The bridge reminds me of Conde McCullough's famous bridges along the Oregon coast, bridges also of the same era. No wonder it has retained the affection of its community for 83 years.

So it is heartening to see that the members of its community decided to spend a bit more than the cost of a new bridge in order to restore the old one. They recognized that aesthetics and historic preservation have a value and that they are worth spending money on to accomplish community goals. It is a rare attitude in today's climate of relentless cost cutting. This step is perhaps easier to take for a city that does not have to reconcile competing claims from across a state.

It is also heartening that the designers took a "both. . .and" approach to balancing aesthetic criteria and the undoubtedly difficult technical requirements of the seismic retrofit. Frequently, technical needs are given first priority, and aesthetic features made to fit into whatever space remains. In this case the designers kept working on technical solutions until they found ones that accomplished both the seismic requirements and the aesthetic criteria, at the same time. For years to come the citizens of Del Mar will bless them for their persistence.