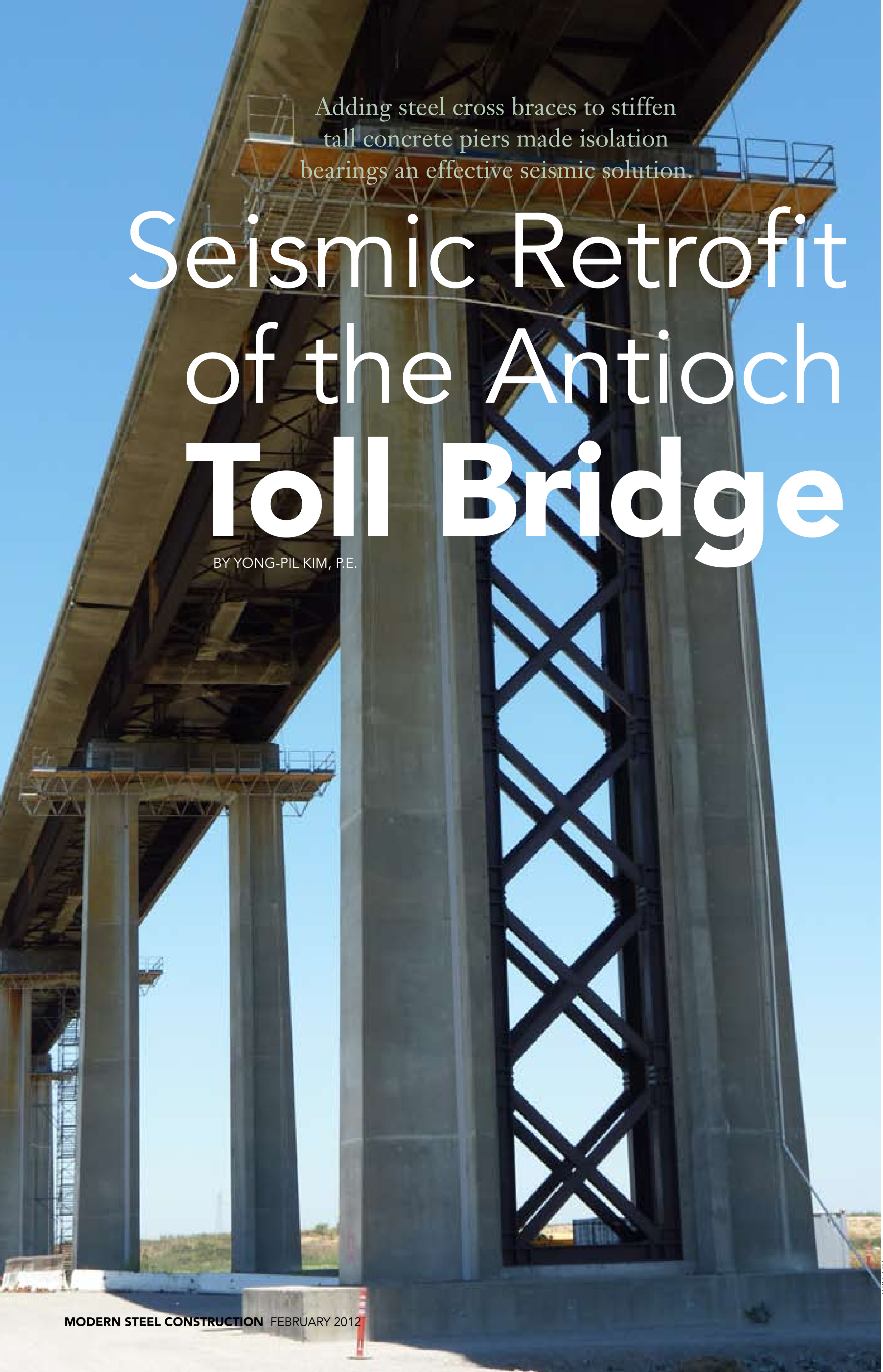


Y.P. Kim

Adding steel cross braces to stiffen tall concrete piers made isolation bearings an effective seismic solution.

Seismic Retrofit of the Antioch **Toll Bridge**

BY YONG-PIL KIM, P.E.

Steel braces were added to stiffen the columns of the 20 tallest piers as part of a seismic retrofit on the Antioch Toll Bridge over the San Joaquin River in Northern California.

THE SEISMIC RETROFIT of the Antioch Toll Bridge in Northern California consists of replacing the existing bearings at all 39 piers and at the abutments with seismic isolation bearings. In order to make the isolation bearings work effectively, it also was necessary to install steel bracing in the tall piers to make the pier portal frames stiffer.

Caltrans owns and operates Antioch Toll Bridge, but the funding came from the Bay Area Transit Authority (BATA), which also managed oversight of the retrofit construction. The total steel used for the cross bracing was 1,850 tons, all of which was fabricated and prime painted by Brooklyn Iron Works, Inc., Spokane, Wash. Eighty-two single-surface friction pendulum isolation bearings were supplied by Earthquake Protection Systems, Inc., Vallejo, Calif.

The main structure is 8,650-ft long with 40 spans arching over San Joaquin River. The midsection of the bridge rises as high as 147 ft to allow for ship passage. The superstructure consists of two weathering steel plate girders that are continuous over the piers. The girders are in excellent condition, having formed the expected uniform protective outer coating with no degradation in structural capacity.

Antioch Toll Bridge is one of the last two toll bridges to be retrofitted in Northern California. It was constructed in 1978, so the lessons learned from the San Fernando Earthquake of 1971 were implemented in the original design. For this reason, the bridge was long considered to have sufficient earthquake resistant features and deemed safe. However, reevaluating the bridge based on the latest seismic design criteria and an extensive geotechnical investigation, Caltrans concluded that the bridge needed to be retrofitted.

The bridge's average daily traffic is 15,000, a relatively small number compared to other toll bridges in Northern California. However, because it crosses the San Joaquin River, which is an important navigational channel, its seismic retrofit is based on the Safety Evaluation Earthquake criteria with a 1,000-year return probability. The project-specific SEE design criteria are based on "No Collapse" with permissible damages in parts of the pier pile groups and the deck expansion joints.

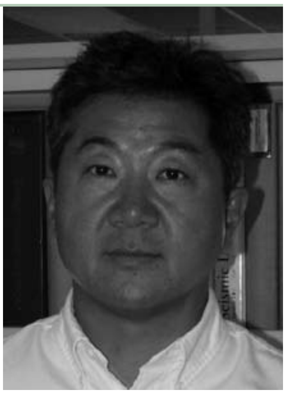
The analysis of the existing bridge exposed several deficiencies. First, there is a possibility of shear failure in the existing columns and the bent caps. Second, the existing rebar couplers at the base of the columns could fail prematurely. Third, the existing pile foundation system could fail undermining the stability of the bridge. In addition, the existing pin hanger hinges could fail due to possible misalignment of the girders.

Although the existing superstructure carries only two traffic lanes and is relatively light , isolating the superstructure proved to be an effective solution. Single-surface friction pendulum isolation bearings were selected for the design due to the restricted vertical clearances. Two sizes were used in order to accommodate different magnitudes in loading conditions. The larger bearings are 7.2 ft in diameter, 9.2-in. thick and have 23 in. of maximum displacement capacity. The smaller ones are 5.8 ft in diameter, 7.2-in. thick and have 20 in. of maximum displacement capacity.

By isolating the superstructure, the base shear at the piers dropped between 23% and 79%. Similar reduction in shear demand in the bent caps was observed. In addition, it reduced the tensile forces in the column vertical rebar. This will eliminate concerns about premature failure of the existing rebar splices by keeping the forces in the rebar within the yield limits. Although the retrofit reduces forces going into the pile foundation, some pile failures are still expected. Most of the pile failure will be in the exterior battered piles that will form multiple plastic hinges. Some interior piles will fail, in some piers, but based on the project-specific "No Collapse" criteria the performance of the substructure is defined as acceptable. This not only reduces the construction cost but also saves the existing river environment from any disturbance.

Two sets of steel cross bracing were installed to stiffen each of the taller piers, then painted brown to match the weathering steel superstructure.

Yong-Pil Kim, P.E., is a senior bridge engineer at Caltrans. He has 23 years of bridge design experience and is the project engineer for the design of seismic retrofit the Antioch Toll Bridge project.



Far left: The main diagonal cross braces are rectangular HSS welded at the cross joints.

Left: All frames were trial fit in the Brooklyn Iron Works shop.

Allowance had to be made for the bevel plate above the isolation bearing in addition to the thickness of the bearing itself.

Steel braces were added between the columns for 20 of the tallest piers in the mid-portion of the bridge, which range in height from 82 ft to 147 ft. The piers consist of portal frames with two hollow concrete columns linked by a hollow concrete bent cap. Because the original, unbraced frames were flexible under lateral loading, it was necessary to make them stiffer for the isolation beatings to be effective. Accomplishing this through the use of bracing also reduced the seismic loading in the columns. Steel braces were the obvious solution, because of their relatively light weight and ease of installation.

The main diagonal cross braces consist of HSS 12×8⅝ welded at the cross joints. There are two sets of bracing per pier. Each set of braces aligns with the webs of the hollow columns in the transverse direction to make the concrete and steel bracing work integrally in resisting shear. The cross braces are connected on each side to vertical W14×211 wide-flange beams, ASTM A709, Grade 50W, which in turn are connected to the columns through a cast-in-place concrete pedestal. The combination of rebar attached to the side of the existing concrete pier and the shear studs attached to the beam flange cast within the concrete pedestal will solidly link the two elements. Connection plates welded to the ends of the braces are bolted onto the inside flanges of the wide-flange beams.

Field Installation

Jacking of the girders was carried out with live traffic on the bridge deck. Only temporary road closures were necessary when lowering the bearings from the deck. A maximum of ½ in. of lifting of the girders was necessary to release the existing bearings. On many of the piers the jacking system was supported on two solid steel cylinders that were inserted into holes cored in the concrete bent cap. Simultaneous jacking was carried out at four points on each pier to unload the existing bearings.

Even though relatively thin bearings were selected it was still necessary to remove some existing concrete at the top of the bent cap to accommodate the bevel plate over the bearing and the grout pad underneath and still keep the same vertical profile of the existing bridge deck. This was accomplished by using a cable saw to cut and remove as much as 4.5 in. of the top of the existing concrete bent caps. Because this process either cuts through the exiting top transverse bent cap reinforcements or weakens their bonding, additional post tensioning was installed in transversely cored holes and lightly stressed. This will preserve the moment capacity of the bent cap. Even though some of the bent caps were up to 32-ft wide, coring through them could be achieved fairly accurately.

The bridge has four intermediate hinges that were retrofitted with an internal shear key system in order to prevent any possible transverse misalignment of the girders with respect to each other across the hinges. The hinges are connected with a pin hanger system. Any out of plane bending would make the hinge vulnerable and although there are stay plates attached to both top and bottom flanges they are not strong enough to resist in a major earthquake.

The seismic retrofit of the Antioch Toll Bridge based on isolating the superstructure

Steel cylinders inserted through holes cored in the pier cap provided a base for hydraulic jacks, which lifted the girders to allow replacement of the original bearings with isolation bearings.

Pile Group Performance

Even with the isolation of the superstructure there will be partial failures in the existing pile groups under the design earthquake. Because the project-specific design criteria are based on preventing the collapse but not immediate functionality of the bridge, the partial failure of the pile groups after a major earthquake is acceptable as long as the bridge can still support its own weight.

All the piers have battered exterior piles, which will absorb much of the seismic forces and likely form plastic hinging in the piles. The interior vertical piles will deflect and ride out the seismic forces more easily. Due to the exterior battered piles, the pile group rigidly linked with the pile cap will not only translate laterally but also will rotate. In order to analyze the maximum displacement capacities of the pile groups, the displacement and rotational capacities of each pile group had to be calculated. This was compared with different stages of pile group failure to ascertain their ultimate capacities.

The as-built condition was analyzed with a global dynamic analysis based on acceleration response spectra (ARS) with an equivalent 6x6 matrix stiffness for the pile groups at each piers. The retrofitted bridge was analyzed with a global dynamic analysis using time histories. SAP2000 was used for the dynamic analyses.

is a simple but effective solution. Implementing this scheme by adding steel cross braces to the concrete pier frames was an ideal match. Shop fabricated segments of the steel braces were field assembled with bolted connections and the bracing can be easily integrated to the existing concrete frame by connecting the two different elements through a cast-in-place concrete pedestal. Due to steel's light weight, the additional weight of the bracing could be accommodated within the capacity of the existing foundation. Not requiring a foundation retrofit meant big savings in the construction cost and also minimized the disturbance to the sensitive environment. MSC

Owner and Engineer
California Department of Transportation (Caltrans)

Steel Fabricator
Brooklyn Iron Works, Inc., Spokane, Wash. (AISC Member)

General Contractor
California Engineering Contractors, Inc., Pleasanton, Calif.