THE SAN FRANCISCO – OAKLAND BAY BRIDGE

By Ronald F. Middlebrook, S.E. and Roumen V. Mladjov, S.E.

Figure 1: Bay Bridge with new east crossing.

The San Francisco-Oakland Bay Bridge is one of the greatest American bridges. Built during the Great Depression, the bridge soon became known as the "working horse of Northern California," carrying the heaviest traffic in the region.

General Information

The San Francisco – Oakland Bay Bridge opened to traffic in 1936. It connects San Francisco and Oakland and is the busiest vehicular link in Northern California (*Figure 1*).

The bridge is actually several structures with distinctly different systems, strung together to form about a 8.5-mile (13.7-km) cross-bay roadway, nearly 4.4-miles over water (7.1km). The main portions of the original were:

- West crossing: Nearly 2 miles (3,140 m) from San Francisco to Yerba Buena Island (YBI), including a twin suspension bridge with central spans of over 2310 feet (704 m) (*Figure 2*).
- YBI segment: 1800 feet (549 m) featuring a tunnel and short concrete viaduct.

Figure 2: West crossing.

"This marks the physical beginning of the greatest bridge yet erected by the human race."

President Herbert Hoover at the groundbreaking ceremony, 1933

- East crossing: A more than 2-mile (3,417 m) crossing from YBI to Oakland, consisting of several different steel truss systems: four short (approximately 288-foot; 88 m) spans on YBI, followed by the 2420-foot-long (738 m) cantilever structure (*Figure 3*), then five deep through-truss spans at 509 feet (155 m), fourteen deck-truss spans at 288 feet (88 m), and the remainder on simple land-based steel structures.

The original bridge was designed by Ralph Modjeski, Charles Purcell et al. and built by American Bridge Company using steel from United States Steel. At the time of completion, it was the longest bridge in the world and featured the second longest suspension span (2310 feet; 704 m), the third longest cantilever truss span (1400 feet; 427 m), the deepest pier foundation (243 feet; 74 m) below water surface at low tide), and the largest bored tunnel. The west crossing was the only major bridge with two consecutive suspension spans.

The bridge, with its three major segments, is listed on the National Register of Historic Places (NRHP). The Register's comment is: "One of the largest and most important historic bridges in the country."

Figure 3: East crossing (to be demolished).

BRIDGE ELEMENT	ORIGINAL EAST BRIDGE	NEW EAST BRIDGE
Total Length miles (meters)	2.1 (3,377)	2.2 (3,513)
Main Span feet (meters)	1400 (427)	1266 (386)
Secondary Spans feet (meters)	509 (155)	525 (160)
Traffic Lanes	10	10
Vehicles per Day	280,000	324,000
Construction Time (years)	3.5	11.75
Completed	1936	2013
Steel psf (kg/m^2)	85 (416)	347 (1,694)
Cost in US $ Millions	78 (not comparable)	6,450

President Herbert Hoover, who was originally a mining engineer, had followed the development of the design of the bridge during his presidency. He was particularly interested in its effect on employment in trying times. Calling this project, "*The greatest bridge yet erected*," shows its importance to Hoover.

The entire bridge deserves its exalted historic credentials, from the graceful sweep of the west crossing suspension structure, through the YBI tunnel and viaduct, to the steel cantilever truss section, to the through-truss and deck-truss spans. It was built in just 3½ years, at a cost then estimated at $78 million. It was, and still is, one of the greatest engineering achievements of the 20th century.

Design and Construction

The Bay Bridge is a double-decker. The original design featured six automobile lanes on the top deck (three in each direction). The bottom deck provided three truck lanes and two lanes (one in each direction) for an interurban commuter train. Around 1960, the arrangement was converted to five eastbound lanes of traffic on the lower deck and five westbound lanes on the upper deck.

The bridge was designed and built using state-of-the-art techniques available in the 1930s. For example, the engineers specified the highest-strength steel available for critical elements. Nickel (55 ksi; Grade 380 MPa) and silicon steel (45 ksi; Grade 311 MPa) for the east crossing make up 62% of the total steel used there, and 72% of the cantilever section. Even the carbon steel used in this bridge was higher-strength (37 ksi; Grade 255 MPa) than is normally used today. High-strength cable steel (120 ksi; Grade 828 MPa) was specified for the west crossing suspension cables. The entire bridge required 167,100 tons (151,593 metric tons) of structural steel, or 115 psf (561 kg/m^2).

The Bay Bridge and its neighbor, the Golden Gate Bridge (completed in 1937), represent the culmination of more than 100 years of development of bridge engineering and construction in the United States. To fully appreciate the achievement of completing the construction so quickly, consider the technical level of the industry at the time. In addition to the lack of modern devices – heavy equipment, vehicles, cranes, etc. – all steel connections were made using rivets, requiring much more time and labor than modern high-strength bolting and welding. Compare this achievement with the 12 years it took to build the new replacement bridge just for the east crossing!

Amazingly, the 167,100 tons (151,593 metric tons) of steel used for the entire Bay Bridge in 1936 is considerably less than the tonnage that the California Department of Transportation (Caltrans) reported for building just the superstructure of the new east crossing replacement – 266,750 tons (242,000 metric tons), or 347 psf (1,694 kg/m^2). A testament to the wisdom of the design for the Bay Bridge's west crossing is that, 62 years later, Japanese engineers chose a very similar design for the towers of the longest bridge span in the world: the Akashi-Kaikyo (or Pearl) Bridge, with a central span of over 6530 feet (1,991m).

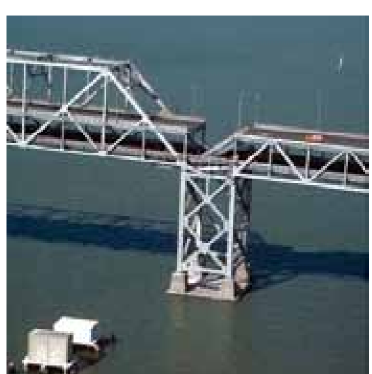

Figure 4: Local damage to the east crossing.

Earthquake Damage

The bridge's east crossing was locally damaged during the Loma Prieta earthquake of 1989. A 50-foot (15-m) section of the top deck slipped off its support at an expansion joint; that end of the section then collapsed onto the lower deck (*Figure 4*). One motorist was killed.

Caltrans subsequently decided to replace the entire east crossing, calling it an Earthquake Safety project; an important decision because it meant that only the pre-existing traffic capacity would be restored. After several years of discussion, planning and design, construction on the new east crossing finally began in January 2002, and it was completed in September 2013.

West Crossing Improvements and East Crossing Replacement

The west crossing (and its approach) underwent seismic improvements in a five-year project beginning in 1999, at a reported cost of approximately $759 million. The improvements included massive rollers installed between the roadway and bridge supports and 96 new viscous dampers inserted at critical points to allow movement. The bridge's twin suspension spans were strengthened by adding new steel plates and replacing half a million original rivets with almost twice that many high-strength bolts. New bracing was added under both decks, and all of the "laced" truss diagonals connecting the upper and lower road decks were replaced. In total, the project added about 8500 tons (7,710 metric tons) of structural steel.

The east crossing replacement was designed by T.Y. Lin International, Moffat & Nichol Engineers, Weidlinger Associates and Donald MacDonald Architects. It is comprised of a single-tower, self-anchored suspension steel span of 1266 feet (386 m) and a 14-span (525 feet; 160 m each) concrete skyway. The new crossing has added shoulders and a bicycle lane. (Since there is no bicycle lane on the west crossing, it will not be possible to bike the entire length of the bridge.)

The cost is about $6.5 billion for a length of nearly 2.2 miles (3,513 m). Current plans are to demolish all of the original east crossing structures from YBI to Oakland, and presumably recycle as much material as possible. Demolition is currently estimated to cost at least $250 million.

Comparing the two east span bridges – the original (1936) and the replacement (2013) – gives an idea of the efficiency of the old bridge (see *Table, page 27*).

Traffic Capacity and Population Demographics

With only five traffic lanes in each direction, traffic movement is greatly compromised, especially during commute hours. Traffic capacity has remained the same from 1960 to 2012 and is no different with the east crossing replacement.

In 1936, the Bay Area population was about 1,650,000. By 1990, it was about 6,024,000, and by 2010, it was 7,150,000. The projected population in 2025 is 8,880,000, rising to 9,031,500 in 2035 (50% greater than in 1990).

Traffic growth has been even more rapid. When the bridge originally opened in 1936, the traffic equivalent was 50,000 vehicles. As early as 1947, Frank Lloyd Wright called the traffic congestion on the Bay Bridge intolerable. By the late 1990s, this critical highway link carried about 280,000 vehicles on an average day. In 2000, it was evaluated as 324,000 vehicles on average. In other words, the growth in demand has increased nearly six-fold over the past 75 years.

Currently, during commute hours it can take up to 30 minutes to drive the 4.4 miles (7.1 km) from water's edge to water's edge across the bridge. That translates to only 9 miles per hour (14 km/h), and sometimes it is even worse, especially if there is an accident on the bridge.

The idea of supplementing traffic capacity across the bay is not new. Numerous studies over the past 60 years have been conducted for new crossings (both bridges and tunnels). None of these studies were pursued, for environmental, political, economic and other reasons. However, these efforts show a great deal of continuing interest in reducing the pressure on cross-bay traffic.

Figure 5: New east crossing: Skyway and self-anchored suspension bridge (SAS). Courtesy of MTC and Caltrans.

Seeking a rational solution for this "problem," some of the possibilities include:

- **Expanding Bay Area Rapid Transit's (BART) underwater, cross-bay tunnel**. BART has already reached its maximum capacity during peak commute times. Enlarging the system would be fraught with technical difficulties, high cost and environmental problems.
- **Adding more ferries**. The Bay Bridge ended the ferry system era long ago. Ferries imply more automobiles to get to and from the water's edge. This would be a giant step backward.
- **Adding a second bridge parallel to the existing Bay Bridge**. This idea has already proven more practical in other cities around the world.

Considering these limited options, a second bridge seems to be the most logical approach to solve the restricted capacity of the existing bridge. Considering the fact that the replacement of the old East crossing structure took more than 17 years, now is the time to begin planning and designing a completely new second SFO Bay Bridge alongside the present one using the retrofitted, old east crossing structures. The Structural Forum column in this issue (page 50) summarizes the argument for this course of action.▪

References

UNITED STATES STEEL, "The San Francisco – Oakland Bay Bridge", 1936

CALIFORNIA DEPARTMENT OF TRANSPORTATION (CALTRANS), Bay Bridge Project / Fact Sheets, **www.baybridgeinfo.org**

CALTRANS "1st Quarter Report, 2013", **www.dot.ca.gov/baybridge/2013-1QReport.pdf**

"San Francisco – Oakland Bay Bridge Second Crossing", Ronald Middlebrook, Roumen Mladjov, IABSE Conference at Rotterdam, May 2013.

*Ronald F. Middlebrook, S.E. (**ronfranco@gmail.com**), is retired from Middlebrook + Louie in San Francisco, California, and is a Past President of the Structural Engineers Association of Northern California (SEAONC).*

*Roumen V. Mladjov, S.E. (**rmladjov@louieintl.com**), is a Senior Associate with Louie International in San Francisco, California, and was a member of the Engineering and Design Advisory Panel for the Bay Bridge.*

A similar article appeared in the IABSE Conference Rotterdam Report, May 2013.