

reinforced

# concrete

1990 - 2000 RETROSPECTIVE

bridges

# reinforced concrete bridges

## INTRODUCTION

The Concrete Reinforcing Steel Institute is proud to honor five great concrete bridges built between 1990 and 2000. Each stands as a solid testament to concrete's versatility, its cost effectiveness, and its durability. From arches to swing leaves, from foundation to superstructure, concrete is clearly a superior bridge-building material.

Golden Gate Park, in San Francisco California, is home to the very first reinforced concrete bridge, built in 1889. Just as the Lake Alford Bridge heralded the 20th century's advances in concrete bridges, the five concrete bridges showcased in the following pages herald the advances expected in concrete bridges for the 21st century.

These five bridges represent the design and construction industry's most technologically advanced and innovative concrete achievements. The lessons learned, the examples set, the visions accomplished have elevated the art and practice of bridge engineering to an entirely new level.

It is CRSI's mission to turn the technological innovations of today into tomorrow's state-of-the-practice. We sincerely hope that in decades to come, the advances described in these pages will proliferate through the bridge design and construction industry, inspiring the creation of new and magnificent bridges commensurate with their innovative predecessors.



# Natchez Trace Parkway

Franklin, Tennessee

A Pioneering Tribute

. . . concrete as art.

## AWARDS

1994 Design Award Winner, Concrete Reinforcing Steel Institute

1994 Engineering Excellence Grand Award, American Consulting Engineers Council

1994 George S. Richardson Medal, 11th Annual International Bridge Conference

1994 Charles S. Whitney Medal, American Concrete Institute

1994 Award of Excellence, Portland Cement Association

1995 Outstanding Civil Engineering Achievement Award of Merit, American Society of Civil Engineers

1995 Project of the Year Award, Tennessee State Chapter—American Society of Civil Engineers

1995 Presidential Design Award, National Endowment for the Arts

1995 Honored by U.S. Department of Transportation as one of eleven outstanding projects of the past 15 years

1996 Excellence in Highway Design, Federal Highway Administration

1997 First Place, American Concrete Institute 1st Annual Concrete Aesthetics Recognition Program

1999 Top 125 Projects of the Past 125 Years, Engineering News-Record



Some say that buffalo first carved the trail that is now the Natchez Trace Parkway, followed by Natchez, Choctaw, and Chickasaw Indians. Thousands of pioneers, settlers, farmers, and traders followed in their footsteps, creating a transportation lifeline for the region. The Parkway, a 450-mile, scenic two-lane highway between Natchez and Nashville, commemorates this historic route.

Today, a new concrete segmental arch bridge, America's first, is the Parkway's crowning jewel. The National Park Service chose a concrete arch bridge to help preserve the area's beauty and stand as a signature structure and stunning landmark in its own right, a tribute to humankind's need—past, present, and future—to move from place to place.

### **Unobstructed View of the Scenic Terrain**

Two graceful arches support the bridge superstructure. The main arch span is symmetrical, 582 feet long from pier to pier. The second arch is 462 feet long and asymmetrical due to rising topography at the bridge's south end. The arch foundations are cast-in-place concrete thrust blocks bearing directly on limestone bedrock.



## The Building of a Bridge: Simulated Cable-Stay Construction

The bridge includes three cast-in-place concrete piers built using the slip form method. As construction moved from the foundation upward, temporary cable stays were anchored in the top of the pier sections, attached to the arch segments, and post-tensioned.

The arches were erected in progressive cantilever. The first cable stays were anchored in the eighth arch segment from the trust block and then in every succeeding fourth segment. The cable stays and post-tensioning tendons supported the arch until the arch was fully constructed.

Once the piers reached full height and the arches were complete, superstructure erection began, placing the first precast concrete segments on top of the piers. The segments were erected using conventional balanced cantilever construction techniques using a ground-based crane.

The arches are built from 122 precast concrete hollow box segments, 16 feet wide, with walls that vary in depth from 10 feet at the base of the arch to 13 feet at the crown. Unlike most arch bridges, the arches were designed without spandrel columns, giving the bridge an open, airy appearance.

### ***Soaring Over the Valley Floor***

The superstructure is built of 196 precast concrete segmental trapezoidal box girder segments, varying in depth from 7½ feet at mid-span to 14 feet at the piers in order to span the distance between pier and crown without spandrel column support. Maintaining a constant web angle on both sides, but varying the depth, means that the soffit width varies.

This creates one of the most stunning details of the bridge: the pier and soffit widths are equal at the top of the pier, making the structure seem nearly monolithic, as if carved from a single piece of marble. The superstructure rests on two bearing locations, 45 feet on either side of the arch crowns. Elastomeric bearings isolate superstructure movement from arch movement. As a result, only two superstructure expansion joints were needed for the entire bridge, one at each abutment.

Innovative engineering and construction, including the use of precast elements throughout, saved over \$3 million from the owner's original estimate, a clear demonstration of the value of concrete.

*"We approach each concrete bridge as a work of art, an icon for the future."*

—Eugene Figg, P.E., Figg Engineering Group

Owner: National Park Service and Federal Highway Administration

Engineer: Figg Engineering Group

Contractor: PLC Civil Constructors

Structure Type: Concrete Segmental Arch

Overall Length: 1,572 feet

Overall Width: 36 feet

Total Cost: \$10.9 million (bridge only)



# Lake Redding

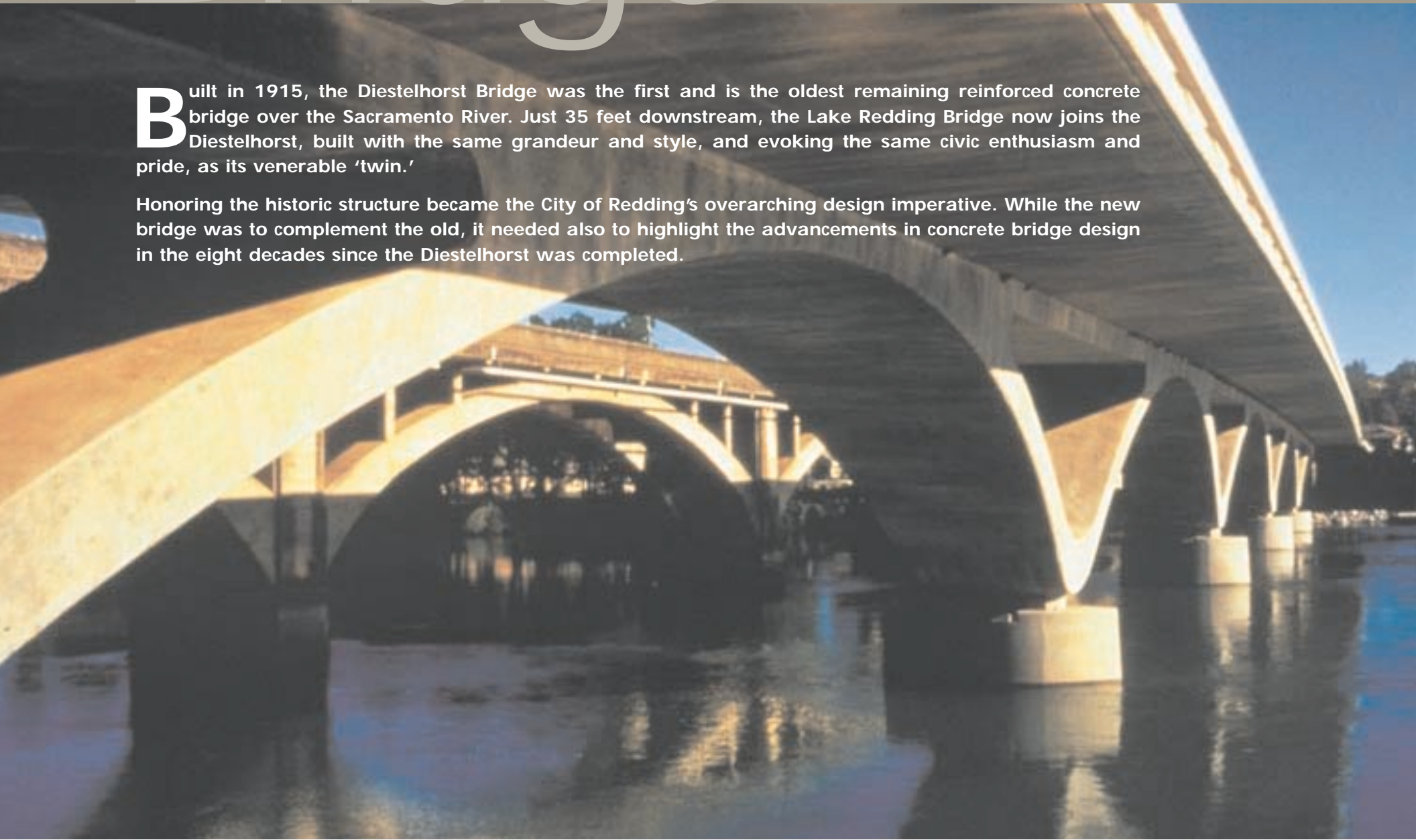
Redding, California

A Tale of Two Bridges

. . . where old concrete meets new.

**B**uilt in 1915, the Diestelhorst Bridge was the first and is the oldest remaining reinforced concrete bridge over the Sacramento River. Just 35 feet downstream, the Lake Redding Bridge now joins the Diestelhorst, built with the same grandeur and style, and evoking the same civic enthusiasm and pride, as its venerable 'twin.'

Honoring the historic structure became the City of Redding's overarching design imperative. While the new bridge was to complement the old, it needed also to highlight the advancements in concrete bridge design in the eight decades since the Diestelhorst was completed.



## Versatility in Form

With an abundant supply of good aggregate in the Western states, concrete was the clear material of choice for bridges in 1915, and remains so today. The two bridges are a study in likeness and contrast, and highlight one of concrete's best features: it can be cast into nearly any size or shape.

The five-span arches of the new Lake Redding Bridge mirror the arches of the historic bridge in both length and position in the river, creating a distinct parallelism. But while the old bridge includes spandrel columns between the deck and arches, the new one does not.

The old bridge connects to its supporting piers with definitive angles, creating five separate, although connected, arches. The arches of the new bridge flow in a continuous sinusoidal wave across the river, with minimal emphasis on support connections.

## Tailored Reinforcing

Designers chose cast-in-place construction to emulate the look and feel of the Diestelhorst Bridge. Thinner-than-normal structural elements, including deck and arches, were specified to ensure that the new bridge does not impose heavily on the old. The superstructure is a single cell box girder, with 14½-foot overhangs on both sides and transverse post-tensioning.

Full-length longitudinal post-tensioning would have been inefficient, because tensioning forces would be transferred from the box girder through the arch rib into the piers, and require a larger pier. Designers knew that as they increased the pier size, the box girder pre-stressing requirements would increase.

To avoid this circular dilemma, only the end spans—at 157 feet long, the longest in the new bridge—were post-tensioned. The remaining spans, each 115 feet long, were conventionally reinforced, and the piers remained a reasonable structural size.

To replicate the look of the old bridge's massive piers, designers created a nonstructural, torpedo-shaped concrete shell around the new piers that also improved hydraulic efficiency and aesthetics. Concrete serves and prevails, then and now.

## A Bridge to the Future



Over the years, the narrow Diestelhorst Bridge had become functionally obsolete. Now it enters its golden years as a pedestrian bridge, with the Lake Redding Bridge shouldering vehicular traffic. Citizens of Redding walk the old bridge and admire their new bridge with civic pride. Other bridge alternatives may have been cheaper, but the city council made a commitment to creating a landmark bridge. In doing so, they have spurred an unparalleled urban renaissance. A new city hall and a revamped downtown shopping area have followed in the wake of the new landmark.



*"Its beauty and styling are like a monument, a sculpture. More than anything, this bridge has bolstered the city's cultural ambiance and civic pride."*

— Jerry Aasend, P.E.  
City of Redding Public Works

## AWARDS

1998 Construction Award Winner:  
Northern California and Western  
Nevada Chapter of the American  
Concrete Institute

1998 Concrete Bridge Awards  
Winner, Portland Cement  
Association

1998 City of Redding Urban Design  
Awards for the period 1991–1998

Owner: City of Redding

Engineer: Martin, Rivett & Olson, Inc.

Contractor: MCM Construction

Structure Type: Post-tensioned and  
conventionally reinforced  
cast-in-place concrete arch

Overall Length: 659 feet

Overall Width: 44 feet

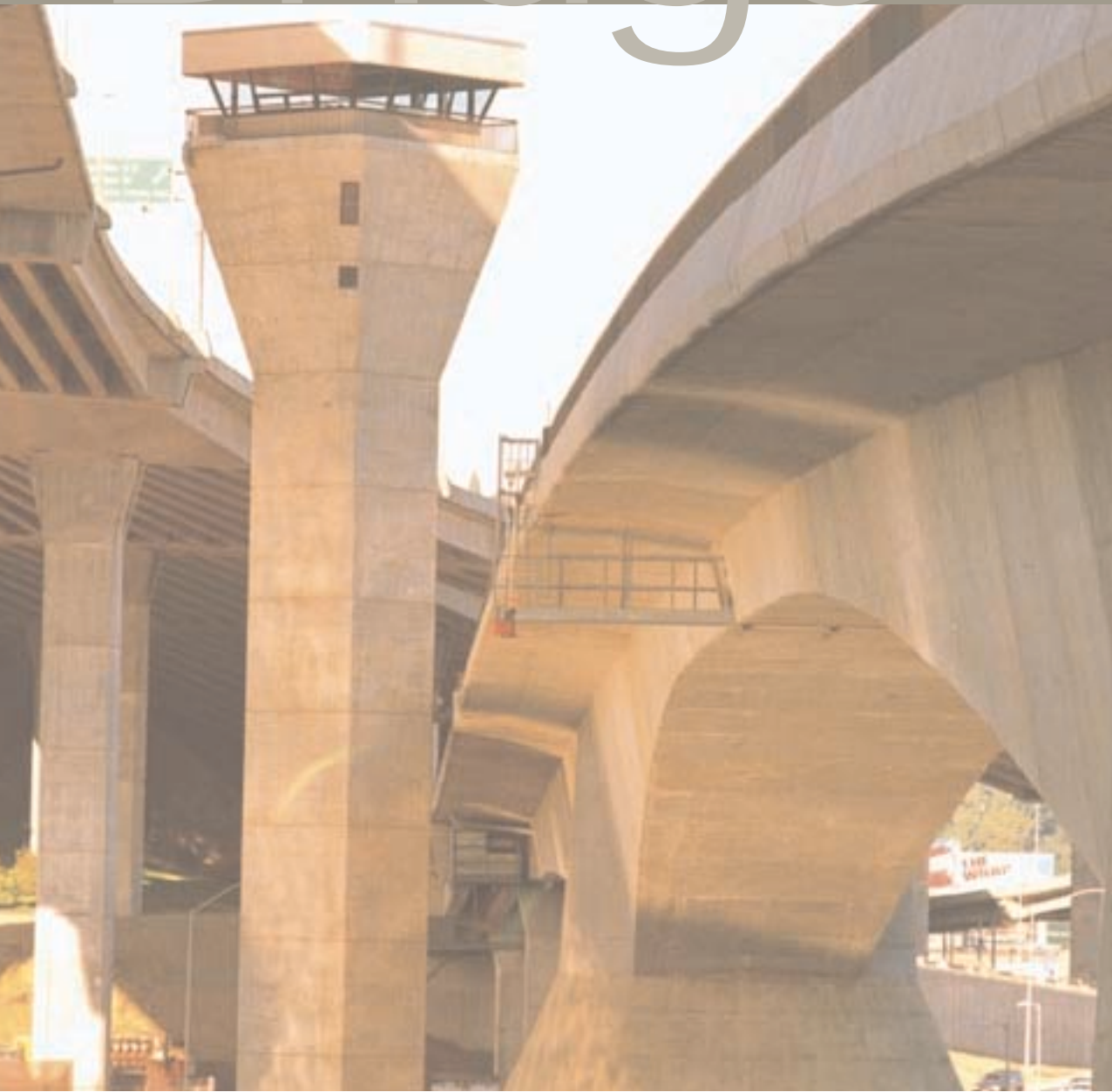
Total Cost: \$5.7 million

# West Seattle Swing Bridge

Seattle, Washington

The Clear Choice for a Clear Channel

. . . concrete opens new possibilities.



At the time that city engineers began to evaluate a replacement for the deteriorating and outdated 1930s-vintage bridge over the Duwamish River, every bridge in the area was a mechanically operated steel bascule. The city's design team broke with tradition, recommending a hydraulically operated concrete double-leaf swing bridge, based on in-depth research.

Concrete's reduced capital and life cycle costs made it the obvious choice over steel. Over time, the city would save by eliminating the need for costly bridge painting, steel inspection, and deck grating replacement. In addition, the concrete swing provides a wider channel opening and greater vertical clearance from the water, reducing the number of openings by 30 percent. Concrete is aesthetically compatible with the adjacent concrete high bridge.

As the city began to operate the new bridge, additional advantages became apparent. The absence of a slippery steel deck grating dramatically reduced the number of bridge accidents.

*"We are extremely pleased with the West Seattle Swing Bridge, and feel that concrete was the right choice for our bridge."*

— Frank Yanagimachi,  
Seattle Transportation

## The True Test

Making the decision to build the world's first hydraulically-operated concrete swing bridge took conviction. Never had such a heavy swing bridge been built. No one was sure the lift-turn cylinder would work.

To make their case, project engineers built a half-scale model of the lift-turn cylinder and ran it through continuous open-and-close cycles for 3 months, simulating 10 years of hard use. The model, taken apart after testing, showed no wear on seals or surfaces. Maintenance crews still use the model for training, to develop a hands-on understanding of how the hydraulics operate and how to maintain the system.

### *Exacting Lift and Swing*

Two 413-foot-long concrete leaves, each weighing 7,500 tons, pivot on a single pier on each bank of the Duwamish. At least six times a day, seven days a week, using a 9-foot-diameter hydraulic cylinder, operators lift the leaves just one inch and swing them open to allow ships to pass.

The bridge was built simultaneously on both sides of the river in the open position. The concrete box girders were cast in place segmentally, starting at the piers and moving outward. After each pour, surveyors checked the alignment, accounting for bridge camber, deck crown, and position relative to its mirror segment.

Misalignment by more than  $\frac{3}{4}$ -inch vertical and  $\frac{1}{4}$ -inch horizontal means the bridge will not close. Extra transverse, longitudinal, and vertical post-tensioning was used to prevent long-term deformations and allow field adjustments. When the bridge leaves were closed for the first time, they fit together perfectly. After nearly ten years of operation, the stiff concrete leaves still open and close with precision.

Owner: Seattle Transportation

Engineer: Andersen Bjornstad Kane Jacobs, Inc.

Contractor: Kiewit-Global Joint Venture

Structure Type: Concrete Double Leaf Swing Bridge

Overall Length: 827 feet

Overall Width: 51 feet

Total Cost: \$33.5 million

## AWARDS

*1992 Achievement Award, National Society of Professional Engineers*

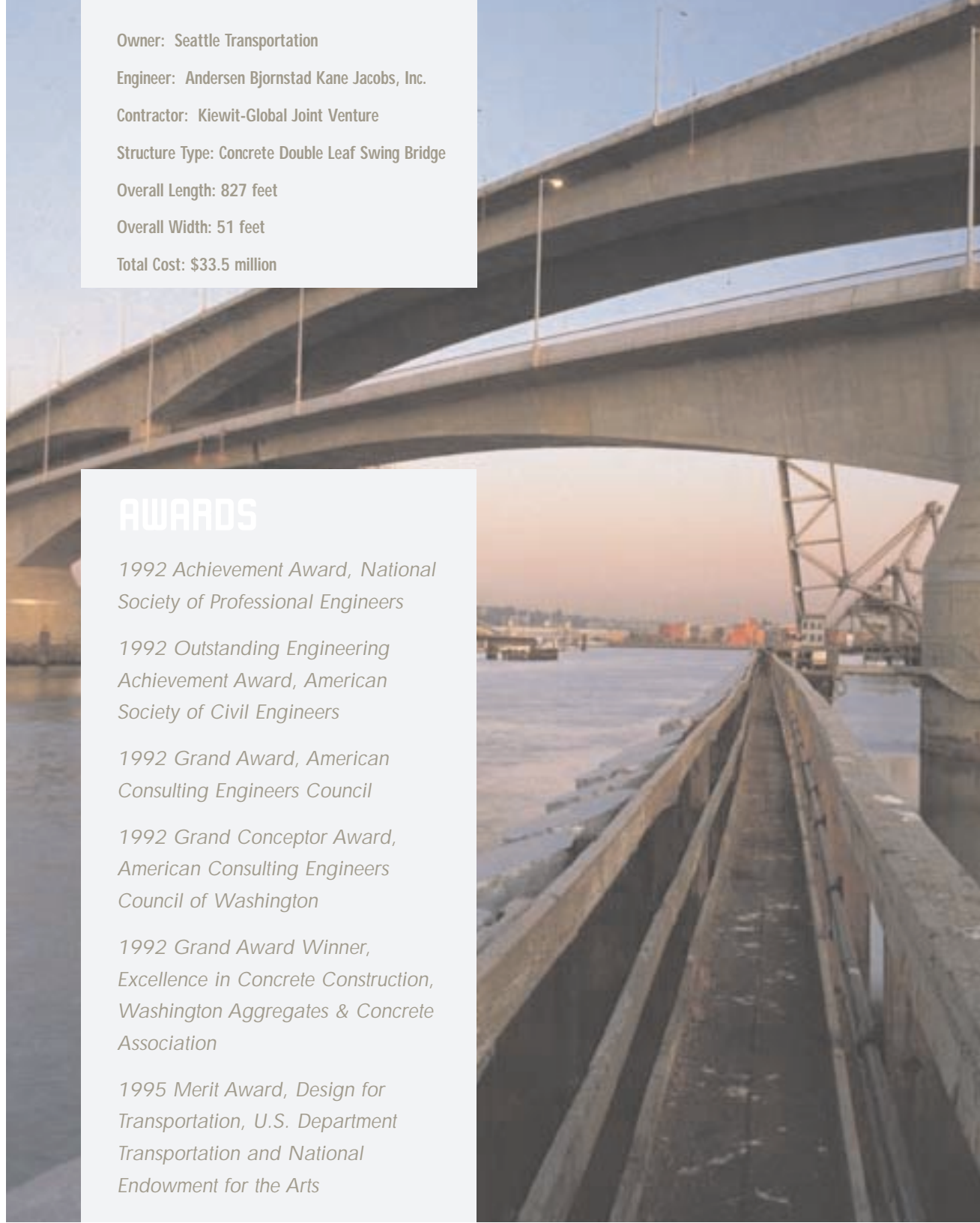
*1992 Outstanding Engineering Achievement Award, American Society of Civil Engineers*

*1992 Grand Award, American Consulting Engineers Council*

*1992 Grand Conceptor Award, American Consulting Engineers Council of Washington*

*1992 Grand Award Winner, Excellence in Concrete Construction, Washington Aggregates & Concrete Association*

*1995 Merit Award, Design for Transportation, U.S. Department of Transportation and National Endowment for the Arts*



# Wabasha Street Bridge

Saint Paul, Minnesota

Versatility in Action

. . . concrete for all seasons.

**T**he Wabasha Street Bridge is a story of concrete, custom-formulated for construction, performance, and style, a story in which concrete, rose once again, to the challenge of demanding design specifications and harsh weather. Concrete created a bridge whose style is reminiscent of Saint Paul's skyscape and whose color is reflective of the adjacent river bluffs. Concrete created a hearty bridge.

*"Concrete proved its versatility on the Wabasha Street Bridge. Every concrete mix was customized for a specific application: high-early-strength for the box segments, low-heat for massive pours, and special forming and coloring for the architectural finishes."* — Kevin Nelson, P.E., City of Saint Paul Bridge Division

## Completely Crack Free

More than a few contractors' eyebrows were raised at the City of Saint Paul's "crack-free" concrete specification. Mass concrete pours like those required for the lower stem of Wabasha Street bridge's piers—over 17 feet square and 30 feet tall—are notorious for cracks that result from rapid exterior cooling relative to slower cooling of the core.



## Material Progression

The first bridge ever to completely span the main channel of the Mississippi River, a wooden Howe Truss bridge, opened for traffic in 1859 at the present location of the Wabasha Street Bridge. It could not survive Minnesota's harsh weather, and was replaced in 1871 with a second wooden Howe Truss, which lasted only 5 years.

The third bridge, an iron Pratt Truss bridge, required expensive maintenance and had to be replaced. A fourth bridge, built in 1889 of iron and soft steel, deteriorated from heavy use and corrosion. The present concrete Wabasha Street Bridge is now the fifth, and expected to be the most durable, to stand at this crossing.

The city's specifications mandated a core temperature of less than 160°F and differential temperature between the core and surface of less than 50°F. Numerical modeling and laboratory testing, followed by field testing and adjustments, were used to create the optimal custom concrete mix.

Seventy percent Grade 100 blast furnace slag, mixed with 30 percent portland cement and chilled water helped control the heat of hydration. With at least nine thermocouples embedded in each pier, the designers were able to prove that the curing temperature could be controlled within the city's parameters. The result: 4,000-psi compressive strength in 56 days and not a single crack.

## A Cozy Blanket

The contractor chose to cast the bridge superstructure in-place because setting up a precasting yard was cost-prohibitive. The superstructure was cast in 16-foot segments, starting at the piers and cantilevering in both directions simultaneously.

Designers knew well in advance that a large percentage of the box girder segments would be cast in winter, but didn't anticipate seven blizzards and average daily temperatures of 13°F. The reinforcing steel was remarkably tolerant of the weather extremes.

High-early-strength concrete was used to speed the curing process, and plastic enclosures housing massive propane heaters warmed the working area to 50°F. Insulating blankets covered the top slab. Yet even with special concrete, insulation, and heaters, each pour was cured in its cozy enclosure for five days before it was exposed to the cold winter chill.

Work accelerated in the summer to six or eight segments per week, although ambient temperatures over 90°F required that the box girders be poured in the cooler nighttime hours. Through day and night, winter winds and summer sun, concrete withstands the test of time.

## AWARDS

*1998 Excellence in Highway Design Merit Award, Major Structures Over \$10 Million, Federal Highway Administration*

*1999 Outstanding Use of Poured-in-Place Concrete, Minnesota Concrete Masonry Association*

*1999 Excellence in Concrete Construction Award, American Concrete Institute Minnesota/Iowa Chapter*



**Owner:** City of Saint Paul

**Engineer:** Toltz, King, Duvall, Anderson & Associates with Figg Engineering Group, Inc.

**Contractor:** Lunda Construction

**Structure Type:** Cast-in-Place Concrete Box Girder

**Overall Length:** 1,250 feet

**Overall Width:** 43 feet each  
(two bridges side-by-side)

**Total Cost:** \$35 million

# Admiral Clarey Bridge

Honolulu, Hawaii

The Newest Pearl in the Pacific

. . . concrete keeps a low profile.

*Admiral Clarey Bridge is the world's longest movable concrete bridge span and one of only six floating concrete bridge structures in the world.*

In response to intense demand for naval housing and administrative facilities, the U.S. Navy undertook the development of Ford Island, approximately 4,000 feet offshore from Pearl Harbor. The development required a new mile-long bridge between Oahu and Ford Islands. In the process, bridge designers would have to meet some demanding criteria:

- The 650-foot-wide channel would have to remain navigable to large ships, such as aircraft carriers, with no overhead height restrictions.
- The design would require a low profile to avoid interfering with the serene setting and views of the nearby U.S.S. Arizona Memorial.
- The materials would have to withstand the severe salt-water conditions of the Pacific Ocean.
- The bridge foundations would be sunk into deep sediment.
- Builders would have to deal with Hawaii's distance from mainland material and equipment suppliers.

Under highly corrosive conditions, reinforced concrete is the only viable material for bridges. Designers of the Admiral Clarey Bridge used concrete to create three bridges in one that creatively met the challenging design requirements. A floating section in the middle creates the channel opening by sliding under a fixed trestle on the Oahu end. A low bridge and causeway fill completes the crossing over shallow waters on the Ford Island end.

### **A Seafaring Bridge**

The 1,035-foot-long movable section includes three connected floating pontoons and steel transition spans on both ends. The 310-foot-long floating concrete pontoons were precast in Tacoma, Washington and towed on barges to Hawaii.

After floating to their assigned positions, the three 5,500-ton sections were individually launched by controlled sinking of their carrying barges. The three sections were then joined while afloat, using high-strength tensioned bolts. The use of precast sections from fabricators far from the construction site proved again that reinforced concrete construction can be economically accomplished anywhere in the world.

### **Full Speed Ahead**

The pontoon moves under the fixed trestle at a speed of around one foot per second and the span takes around 25 minutes to open or close completely. The 4,000-foot-long fixed trestle is made of prestressed concrete girder sections founded on driven concrete piles, just high enough to allow the floating section to slide underneath and to allow small boats to pass without having to open the main channel.

The bridge was named after the late Admiral Bernard Clarey, submariner, former Commander in Chief of the U.S. Pacific Fleet, and one of the Navy's most highly decorated officers. The Admiral Clarey Bridge is a tribute to the versatility and durability of concrete.



### **Withstanding Tropical Salt and Sun**

**Designers incorporated an extensive suite of precautions to ensure that the steel and concrete will stand up to harsh salt-water conditions:**

- *Tough fusion-bonded epoxy coating borrowed from pipeline corrosion technology on all 1,146 tons of reinforcing steel; applied after fabrication, cutting, and bending.*
- *Increased concrete cover over the reinforcing steel*
- *Decreased permeability to salt water to protect the reinforcing steel.*
- *Very low water-cementitious material ratio of 0.38 to minimize cracking.*
- *Deck pavement using concrete and special misting spray nozzles during curing.*

## **AWARDS**

*1998 Concrete Bridge Awards  
Winner, Portland Cement  
Association*

*1999 Outstanding Civil Engineering  
Achievement Merit Award,  
American Society of Civil Engineers*

*“Durability makes  
concrete the  
construction material  
of choice in Hawaii.”*

— Gary Yamagata, P.E.  
Pacific Division Naval Facilities  
Engineering Command

**Owner:** Naval Base Pearl Harbor

**Engineer:** Parsons Brinckerhoff Quade & Douglas

**Contractor:** Dillingham-Manson Joint Venture

**Structure Type:** Fixed/Moveable Floating  
Concrete

**Overall Length:** 4,672 feet

**Overall Width:** 46 feet

**Total Cost:** \$54.4 million (structure only)

# Lake Alvord Bridge

San Francisco, California



1890's photo

America's Very First . . . and still enchanted by concrete.

Ernest L. Ransome was an avid proponent of reinforced concrete. In the mid- to late-1800's, Ransome experimented with various methods to improve the tensile strength of concrete structures. In 1884, he patented the use of twisted steel bars for the reinforcing of concrete.

After building several reinforced concrete buildings throughout San Francisco in the 1880's, Ransome turned his sight to bridges. In 1889, he built the Lake Alvord Bridge in Golden Gate Park, the nation's first reinforced concrete bridge.

The bridge is a single arch, 64 feet wide and 56 feet long. With man-made stalactites hanging from the arch, the Lake Alvord Bridge serves as a whimsical portal into the Children's Quarter at the east end of the park. Although the exact construction methods are not known, Ransome probably used his cold-twisted square steel reinforcing bars longitudinally in the arch.

Lake Alvord Bridge, along with many of Ransome's reinforced concrete buildings, withstood the 1906 and many subsequent earthquakes and is still standing today. Over the past hundred years, concrete bridge building has made incredible technological gains. Bridge designers, constructors, owners and travelers still look with awe and enchantment at the magnificent structures that can be built using Ransome's finest innovation: steel reinforced concrete.

## CONCRETE REINFORCING STEEL INSTITUTE



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Reinforced concrete bridges are an integral part of America's infrastructure. Since 1924, the Concrete Reinforcing Steel Institute has fostered the continued growth of reinforced concrete as an economical, durable, aesthetically pleasing, and extremely versatile bridge construction material.

*Thanks to the Portland Cement Association for providing information and photographs.*