As Easy As "ABC"

Accelerated Bridge Construction Techniques for Large Steel Orthotropic Deck Bridges

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Bridge technology is coordinated in the United States by the Federal Highway Administration (FHWA) for the 50 state departments of transportation, contractors, fabricators, etc. The FHWA held a series of regional seminars to encourage the usage of Accelerated Bridge Construction (ABC) in September 2004, the proceedings of which can be viewed at **www.fhwa.dot.gov/bridge/accelerated/**. The FHWA has encouraged all interested parties to write and share ideas about ways to utilize ABC, and successful case histories. The ABC mantra is "Get In; Get Out; and Stay Out". The goal of any ABC method is to minimize the effects on other stakeholders and achieve the FHWA's desired 100-year service life for a new bridge. Typical stakeholders are commuters, shipping companies, the environment, railroads, etc. FHWA's goal are: 1) to minimize traffic delays while erecting a bridge, 2) to minimize river commerce and harbor shipping delays while erecting a bridge over navigable bodies of water, and 3) to minimize environmental impacts while erecting a bridge.

The Orthotropic Steel Deck System

About 100 orthotropic steel deck bridges exist in North America, and there are about 650,000 bridges in the USA alone. "Orthotropic" comes from orthogonally anisotropic, which means different properties in perpendicular directions. To bridge engineers, it is a 100% steel superstructure in which a myriad of steel pieces are welded together. Other orthotropic structures include welded steel ships, welded steel dam gates, surge barriers, and a large auditorium roof in Europe. A wearing surface material, such as epoxy concrete less than 1.5 inches thick, is placed on top of the solid steel plate to protect it from vehicular tires. On the San Mateo Hayward Bridge in California, the 500,000-square-foot wearing surface, which was placed in 1967, is still working.

The October 2005 issue of STRUCTURE® magazine includes articles that explain orthotropic bridges in more detail, and are available in the archives at **www.STRUCTUREmag.org**. The self-weight or dead load typically exceeds the loadings from vehicular traffic for any long-span bridge over 400 feet. Orthotropic steel deck bridges offer significant benefits to their owners because the lowest final total weight of bridge results in initial cost savings, as demonstrated by an engineering study that was completed for a bridge of 453 feet (*Table 1*).

Four Basic Techniques of Installation

The relationship between erection and fabrication is like a marriage where it is difficult to separate details. ABC tends to utilize more fabrication away from the final position of the bridge. There are four basic techniques that achieve maximum benefit when the lowest gross tonnage superstructure can be erected in the largest possible pieces. Erecting in the largest pieces means the least time at the site, minimizing disruption of commuters or river or harbor traffic. In fact, a concrete superstructure would require three times as many pieces as an orthotropic steel superstructure. The four "ABC" techniques are launching, lifting, heavy moving on multi-wheeled trailers, and floating (*Table 2*).

Innovative bridges from around the world demonstrate a diverse range of success. The challenge is not to overstress or otherwise damage a pre-assembled superstructure during the moving process.

Launching

Launching means that the superstructure is assembled on the sides of the valley, and pushed from one or both sides horizontally to closure. The methods to move a structure in the longest possible pieces demonstrate the ingenuity of the construction engineer. Launching of steel Bailey bridges was completed throughout the world during World War II by the United States military. Surprisingly, only a handful of bridges in this country have been built this way. Even so, American jacks with computer control systems were used to launch the Millau Viaduct in France. *Table 3* provides a representative list of bridges that have been "launched".

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Table 1: Comparison of practical deck options for a 453-feet span by 55-feet wide movable lift span bridge. (This table is based on one originally created and published by Dr. Thomas A. Fisher of HNTB Corporation)

Deck Type Analyzed and Fully Engineered for Comparison	Lift Span Total Weight (tons)	Advantages	Disadvantages
Orthotropic Steel Deck	760	Lowest self-weight results in cost savings for towers, foundations, motors, cables etc.	Lack of current codes, designers required to do their own research and develop their own design software
Exodermic Deck (patented system)	1099	Owner does not have to worry about design, which is provided by manufacturer	Patent holder becomes a "sole supplier", which requires a waiver from FHWA
Partially-filled Steel Grid Deck with Monolithic Overfill	1228	Older historic system where lifespan has been up to 75 years	Has a much higher dead load than orthotropic decks
Lightweight (100 pcf) Concrete Deck – 8 inches thick	1501	Non-proprietary system	Limited number of suppliers for lightweight aggregate. Not much dead weight savings

Table 2: Comparing ABC techniques for bridges

#	Type	Needs	Advantages	Disadvantages
1	Launching	Jacking equipment, temporary components, launching nose and pylons	Used for long viaducts over deep ravines where falsework not practical, if not impossible	Bridge components may be overstressed during erection causing earlier fatigue issues; extra steel plates or increased thicknesses required for "patch" loadings
2	Lifting	Bigger pieces which can be lifted from water	Massive pieces can be installed, such that bridge main spans are erected in days rather than months	Extra steel plates or increased thicknesses required for lifting components; large jacking systems may be expensive
3	Trailers	Ground that can support trailers, reasonably flat site without creeks or rivers	Great for high volume freeway traffic or over railroad tracks as grade separation bridges	High cost to rent patented trailer systems; extra steel plates or increased thicknesses required below trailer components
4	Floating	Water without large wave action	Entire span can be placed	River or harbor traffic may be blocked for several days

Case History Bridge for Launching: Chiapas, Mexico

The 2003 Chiapas Bridge spans the existing deep reservoir waters behind the Malpaso Dam in the state of Chiapas, Mexico. The superstructure has a total length of 3,963 feet and consists of eight continuous spans, most of which are 539 feet long. The water of the lake is very deep, so the bridge is supported on gigantic steel pipe or braced tubular pipe piers, built similar to an offshore oil platform. Launching was the most practical erection solution.

Table 3: List of selected launched bridges

Year	Type	Name	Main Span	Country, Location
1970	Box-Girder	Arkansas River RR	330 ft.	USA, Redland, OK
1992	Plate-Girder	Satigos Parkway	97 ft.	USA, Long Island, NY
2003	Box-Girder	Chiapas	539 ft.	Mexico, Malpaso Dam, Chiapas
2004	Cable-Stayed	Millau Viaduct	1,122 ft.	France, near Millau

The 9,000-ton orthotropic box steel superstructure was pushed ¾ of a mile from one side of the lake to the other after the pipe piers were built. The construction team reviewed the original design details, which is common when launching is used, and created a three-dimensional finite element model to verify stress distribution during the launching since the cantilever nose, or free end, is moving up and down. Construction loading reviews included dead, temperature and wind loading, which constantly change as the nose or tip is pushed over piers and dips downward at the maximum cantilever position. European engineers refer to the localized zones of launching stresses as "patch loading", where construction stresses become very high. These zones were identified, and the construction team modified the details accordingly. Some other changes were authorized as construction change-orders.

The superstructure was shop-fabricated as 102 segments and then transported to one side of the lake on low-boy trailers. The upper and lower U-sections or halves were field assembled in a 1,230-foot-long concrete trench. Next, single-cell box portions were joined together to form just the length of superstructure needed for each day's launch.

The launching system required two types of temporary construction devices: a wedge-shaped, 140-ton steel launching nose to facilitate moving over the bridge piers, and a 148-feet-high steel cable-stayed launching tower to stiffen the 144-feet-long free end. This added another 110 tons of dead load, since it moved with the superstructure. The tower was mounted on top of the superstructure and had eight cables with (31) ⅝-inch-diameter strands each. After enough segments were joined to reach the abutment to the first pier, the launching system was installed and the structure was jacked forward as a cantilever until the launching nose reached the next pier. ASCE's book on launching of concrete bridges shows this standard technique, and more details on Chiapas are published in the proceedings of the 2004 ASCE Orthotropic Bridge Conference, which are available at **www.orthotropic-bridge.org**.

Table 4: List of selected lifted bridges

Year	Type	Name	Main Span	Country, Location
1967	Box-Girder	San Mateo Hayward	750 ft.	USA, San Francisco Bay
1969	Box-Girder	San Diego Coronado	600 ft.	USA, San Diego, CA
1974	Box-Girder	Rio-Niteroi	980 ft.	Brazil, Rio-Niteroi
1974	Box-Girder	Queensway	550 ft.	USA, Long Beach, CA
1976	Steel Arch	Fremont	1,254 ft.	USA, Portland, OR
1984	Cable-Stayed	Luling Bridge	1,256 ft.	USA, Louisiana
1998	Suspension	Akashi-Kaikyo	6,538 ft.	Japan, near Kobe
1999	Cable-Stayed	Tatara	2,883 ft.	Japan, Oshima
1999	Double Bascule	Gateway to Europe	318 ft.	Spain, Cadiz
1999	Single Bascule	Erasmus	172 ft.	Holland, Rotterdam
2003	Suspension	Alfred Zampa	2,390 ft.	USA, Crockett, CA
2007	Cable-Stayed	Stone Cutters	3,343 ft.	China, Hong Kong

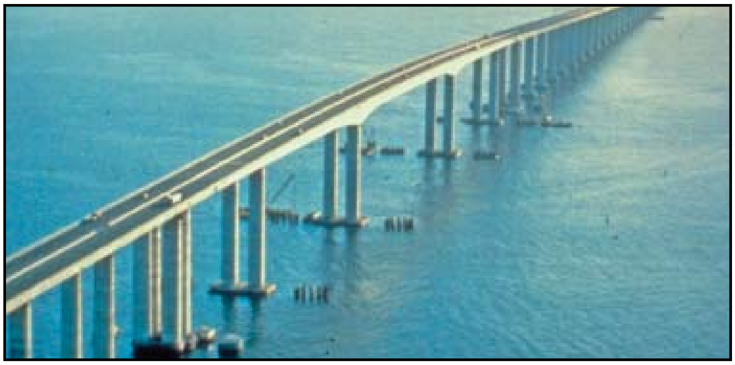

Figure 1: Aerial view of Rio Niteroi Bridge, Brazil. The superstructure is divided into parallel single box girders to support three lanes each of one-way trafic. Photo courtesy of HNTB.

Lifting

Lifting is the vertical lifting of the superstructure. The methods to lift a structure in the largest possible pieces demonstrate the ingenuity of the construction engineer. A list of representative "lifted" bridges is shown in *Table 4*.

Case History Bridge for Lifting: Rio Niterói Bridge

The Rio-Niterói Bridge or "President Costa e Silva Bridge" (*Figure 1*) is a six-lane structure that connects the cities of Rio de Janeiro and Niterói, Brazil. Bridge construction began in January 1969, and the bridge opened to traffic in March 1974. The bridge is 8.25 miles long, with 5.49 miles over sea water. The current average daily traffic is approximately 230,000 vehicles. The Bridge is under private management from 1995 to 2015.

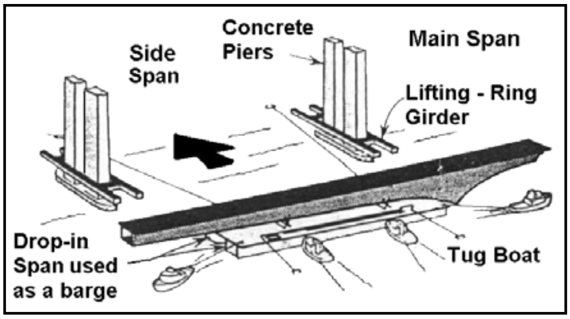

Figure 2: Rio Niteroi Bridge. Orthotropic spans were welded on land and floated out using the drop-in span as the barge itself. Drawing courtesy of Alfred R. Mangus, P.E.

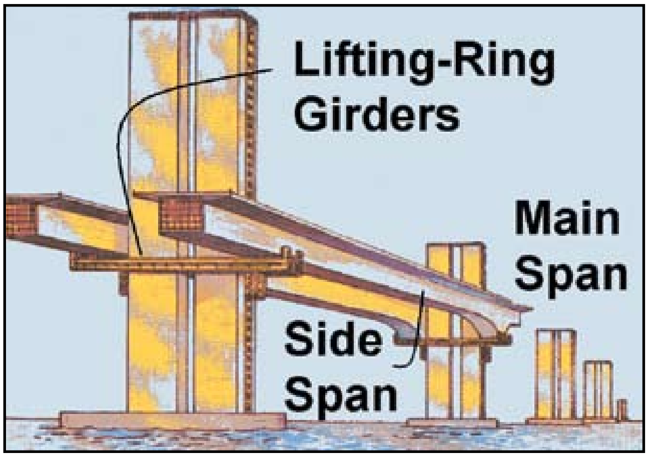

Figure 3: Brazil's Rio Niteroi Bridge's orthotropic spans were fabricated as four idential components and were jacked up in pairs to their final positions 197 feet above sea level . Drawing by Alfred R. Mangus, P.E.

The 2,782-foot-long steel orthotropic parallel box girder spans over the navigation channels. The natural harbor required a main span of 984 feet and a clearance of 197 feet. At the time of its completion, this bridge had the highest central space in the world, in order to allow passage of the hundreds of ships that enter and leave the harbor every month. The approach flight patterns to the city-side airport restricted the height of the structure to 239 feet above the sea water. The superstructure is divided into parallel single box girders to support three lanes each of one-way traffic. It is a variable-depth box girder with a maximum depth of 40 feet above the bridge piers.

Table 5: List of selected bridges moved on multi-wheeled trailers

Year	Type	Name	Main Span	Country, Location
1972	Box	Colusa	105 ft.	USA, Colusa , CA
1997	Arch	Van Brienenoord	943 ft.	Holland, Rotterdam
1997	Curved-Box	Maritime Off-Ramp	195 ft.	USA, Oakland, CA
2002	Box	Rondell	120 ft.	Germany, Oberhof

The orthotropic steel deck navigation span broke a world record. The parallel twin box girders were prefabricated as only three pieces each, or six total. They were welded on land and floated out using the drop-in span as the barge itself. The twin superstructure spans were floated in from both the harbor and ocean sides of the bridge (*Figure 2* shows one span floating in). Lifting ring girders worked like elevators using the final concrete piers to lift up the 850-feet-long side spans. These four identical components were jacked up, as pairs, to their final positions 197 feet above sea level. (*Figure 3)* The steel orthotropic side spans were jacked simultaneously from both sides of the piers to balance the tremendous loadings. Next, the two identical 750-foot-long drop spans were lifted up as a pair. HNTB's design won the 1975 "Grand Conceptor" award in the engineering excellence competition of the American Consulting Engineers Council (CASE).

Heavy Moving On Multi-Wheeled Trailers

Heavy moving on multi-wheeled trailers is when large pieces are moved to their final positions by means of special patented multi-wheel "self-leveling" trailers. These machines are made in Holland, Belgium and Germany. *Table 5* provides a representative list of bridges that have been "trailered".

Case History Bridge for Trailers: Rondell Pedestrian Bridge

The Rondell is a three-span pedestrian grade separation bridge across the autobahn B247 (Rennsteig crossing). The superstructure is a steel box girder orthotropic deck bridge. The contractor fabricated, delivered and erected the complete steel construction including corrosion protection coating in 2002 on multi-wheeled trailers. The bridge's main span is 120 feet in length and 10.7 feet in width (*Figure 4*).

Floating

Floating is when large completed portions of the superstructure or an entire span are floated into the final position. A list of representative "floated" bridges is shown in *Table 6*.

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Figure 4: Rondell pedestrian variable deep orthotropic steel box girder bridge in Germany. Photo courtesy of Donges Steel Company, Germany

Case History Bridge for Floating: Apollo Bridge

The Apollo Bridge, winner of the 2005 Outstanding Civil Engineering Achievement award from ASCE, crosses the Danube River to link the Slovakian capital of Bratislava to the city of Petrzalka. The 741-foot-long steel arch was conceived by Bratislava officials to make a bold aesthetic statement. It carries 90,000 vehicles daily, as well as pedestrians, bicycles and a large number of utilities. The final design by local consultant Dopravoprojekt is a shallow steel tied arch with a slender road deck suspended on cables below. The bridge crosses the main navigation channel on the north side of the river to a pier at the edge of the river on the opposite side. The girders are suspended by a system of stays on two inclined arches, known as "Basket Handles" or "Nielsen Arches", first used by a Danish Engineer. The longitudinal main girders function as a longitudinal tie beam or two tied arches.

The arch is an all-welded steel orthotropic steel deck structure that was fabricated in Hungary and the Czech Republic and delivered by road in elements weighing up to 77 tons. The 5,780-ton steel arch orthotropic main span structure was constructed on dry land (*Figure 5*). It was erected on the left bank alongside the river, with one pot bearing placed on left bank pier. The radiating pattern of cables was tensioned to part of its full loading (*Figure 6*). The free end of the bridge was radially pivoted using hydraulic jacks and winches. To facilitate this pivot operation, the free end's temporary construction utilized a curved steel beam mounted on a falsework platform that in turn was mounted on a pontoon. The orthotropic steel deck bridge's flexibility allowed for additional torsional stresses as the pivot operation took place. To allow this pivot operation to continue across the river, river traffic had to be suspended for five days until the bridge was mounted onto its permanent pier on the right bank.

During the entire construction process, both the geometry of the bridge and the internal forces were monitored in detail and analyzed. The five-day operation was eventually completed successfully. The bridge was permanently anchored into position. Next the pot-bearing was grouted, converting it to a fixed bearing. The cables were re-tensioned and other work was completed.

Figure 5: Apollo Bridge, Slovakian Republic. The left end of the bridge was slid on a curved steel beam onto falsework platform on top of a pontoon. Photo courtesy of DYWIDAG Systems International, Germany.

Figure 6: Apollo Bridge, Slovakian Republic - looking upward at basket handle arch and bare orthotropic steel deck prior to floating across the river. Photo courtesy of DYWIDAG Systems International, Germany.

Table 6: List of selected bridges that were floated into place

Year	Type	Name	Main Span	Country, Location
1965	Suspension	Severn	3,277 ft.	UK, near Chepstow
1972	Floating	US Navy	20 ft.	Vietnam, Da Nang
1982	Floating	Valdez City Dock	200 ft.	USA, Valdez, AK
1992	Floating	Bergøysund	200 ft.	Norway, near Kristiansund
1994	Floating	Nordhordland	382 ft.	Norway, Knarvik - Steinestø
2002	Floating Arch Swing Bridge	Yumeshima-Maishima	1,000 ft.	Japan, Osaka
2005	Floating an Arch	Apollo	741 ft.	Slovakia, Bratislava

ASCE Conference and the Future of Large Orthotropic Bridges

The next ASCE Orthotropic Bridge Conference will be held in August 2008 in Sacramento, California, to continue to share this technology. About 200 engineers from eleven countries attended the 2004 event, the proceedings of which are available from ASCE.

Bridge site visits can be extremely valuable for learning about very complex projects. Major USA projects in construction that have orthotropic steel decks include the Tacoma Narrows Three Suspension Bridge in Washington, redecking of the Bronx-Whitestone Suspension Bridge in New York, and the $1.6-billion self-anchored suspension bridge for I-80 in San Francisco Bay, California. American engineers and construction equipment continue to help design and build orthotropic steel bridges in other countries, including China. The world's largest clear spans for suspension, cable-stayed, floating, movable span, and box girder bridges are all orthotropic steel bridges.▪

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Carl, Alfred and Jay have all participated in FHWA's ABC programs as conference speakers.

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