# More Existing Movable Bridges Utilizing Orthotropic Bridge Decks

Performance / Construction / Maintenance or Structural Elements
For Heavy Movable Bridge Symposium Nov 2006 Orlando, FL

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GATEWAY TO EUROPE BRIDGE, SPAIN Photo Courtesy of courtesy of IABSE & Dr. Juan José Arenas de Pablo [ Figure # 1]

HALSSKOV BASCULE BRIDGE DENMARK Photo Courtesy of Mr. Ove Sorensen, PE OVS@cowi.dk, of COWI Consulting Engineers[Figure # 2]

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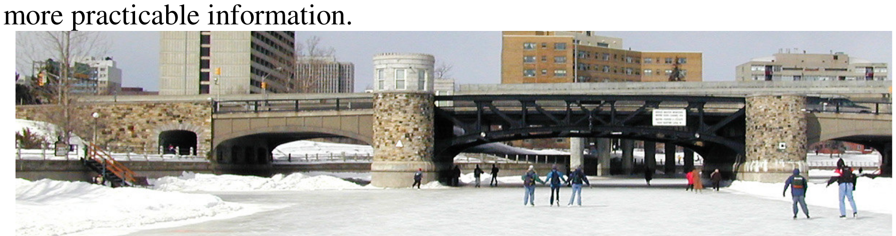
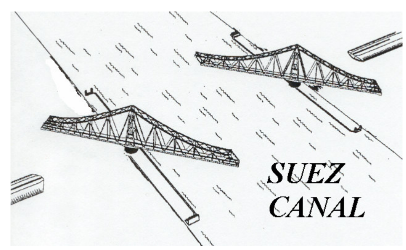
**Abstract**: Movable Bridges with Orthotropic steel decks in North America are very rare. This paper will describe more successful bridges built outside of North America. Many in North America feel that orthotropic steel decks are too challenging to design and offer little benefit to the owners of movable bridges. The advantages will be summarized. This is a continuation of the 2000 paper Existing Movable Bridges Utilizing Orthotropic Bridge Decks. Additional bridges from Europe and Asia are selected to demonstrate the complete range of all types such as the double swing bridge; the floating movable bridge; the skewed Bascule Bridge, and the double leaf bascule bridges, such as the Gateway to Europe Bridge in Spain. New ideas collected from www.orthotropic-bridge.org will be discussed. Key issues such as Dr. John Fisher's fatigue resistant detailing and other updates will be summarized. A comprehensive reference list will be provided to assist in obtaining more practicable information.



Ice-skating below the Pretoria Bascule Bridge Ottawa, Canada [Figure 3]
Photo Courtesy of City of Ottawa




Suez Canal Bridge at El Ferdan drawing Courtesy of Schematic courtesy of Tomlinson, G K ; Weyer, U.; Maertens, L.;Binder B. [ Figure # 4]

# INTRODUCTION:

This paper will identify more imaginative steel deck bridges built and currently in operation. The first paper was written in 2000 for the HMS Symposium and this is intended to be a part two continuation, but also a stand-alone document. Bridges with orthotropic steel decks in North America are still less than about 100 bridges in North America with orthotropic steel decks. There are about 650,000 bridge structures in the U.S.A. Bridges previously discussed were as follows:

| Year | Type | Name | Main Span L x W | Country, Location |
|---|---|---|---|---|
| 1931 | Vertical Lift | Burlington Bristol * | 540-ft x 27-ft | USA, Burlington, NJ & Bristol, DL |
| 1938 | Vertical Lift | Harlem River * | 320ft x 72-ft | USA, New York City |
| 1960 | Vertical Lift | Guabia | 183ft x 18.3M | Brazil, Porto Alegre [ ref. # 5 & 6] |
| 1988 | Vertical Lift | Danziger | 320ft x 108-ft | USA, New Orleans [ ref. # 7] |
| 1990 | Vertical Lift | Severnaya Divina | 84-M | Russia, Arkhangelisk [ ref. # 8] |
| 1990 | Vertical Lift | | 120.45-M | Russia, [ ref. # 8] |
| 1968 | Articulating Ramp | Cordova Ferry Terminal | 119-ft x 16-ft | USA, Cordova, AK |
| 1995 | Articulating Ramp | Roll-On Roll-Off | 2-lane x10-M | Ireland, Dublin |
| 1995 | Articulating Ramp | Roll-On Roll-Off | 200-ft x 29.5-ft | USA, Valdez, AK |
| 1968 | Floating | US Navy Pontoons | 2-lane X 24-ft | Vietnam, Da Nang |
| 1972 | Drop-in | Colusa | 105-ft x 38-ft | USA, Colusa, CA |
| 1973 | Single Bascule | Miller Sweeney | 127-ft | USA, Oakland, CA |
| 1985 | Single Bascule | Breydon | 30.8-M | UK, Britain, Breydon |
| 1999 | Single Bascule | Erasmus | 172 -feet | Holland, Rotterdam |
| 1970 | Single Bascule | Wapole Island | 109-ft | Canada, Wapole Island |
| 1995 | Double Swing | Naestved | 22-M | Denmark, Naestved |
| 2001 | Floating Swing | Yumeshima - Maishima | 1000-ft x 127-ft | Japan, Osaka aka ( Yumemai Bridge of Osaka). |

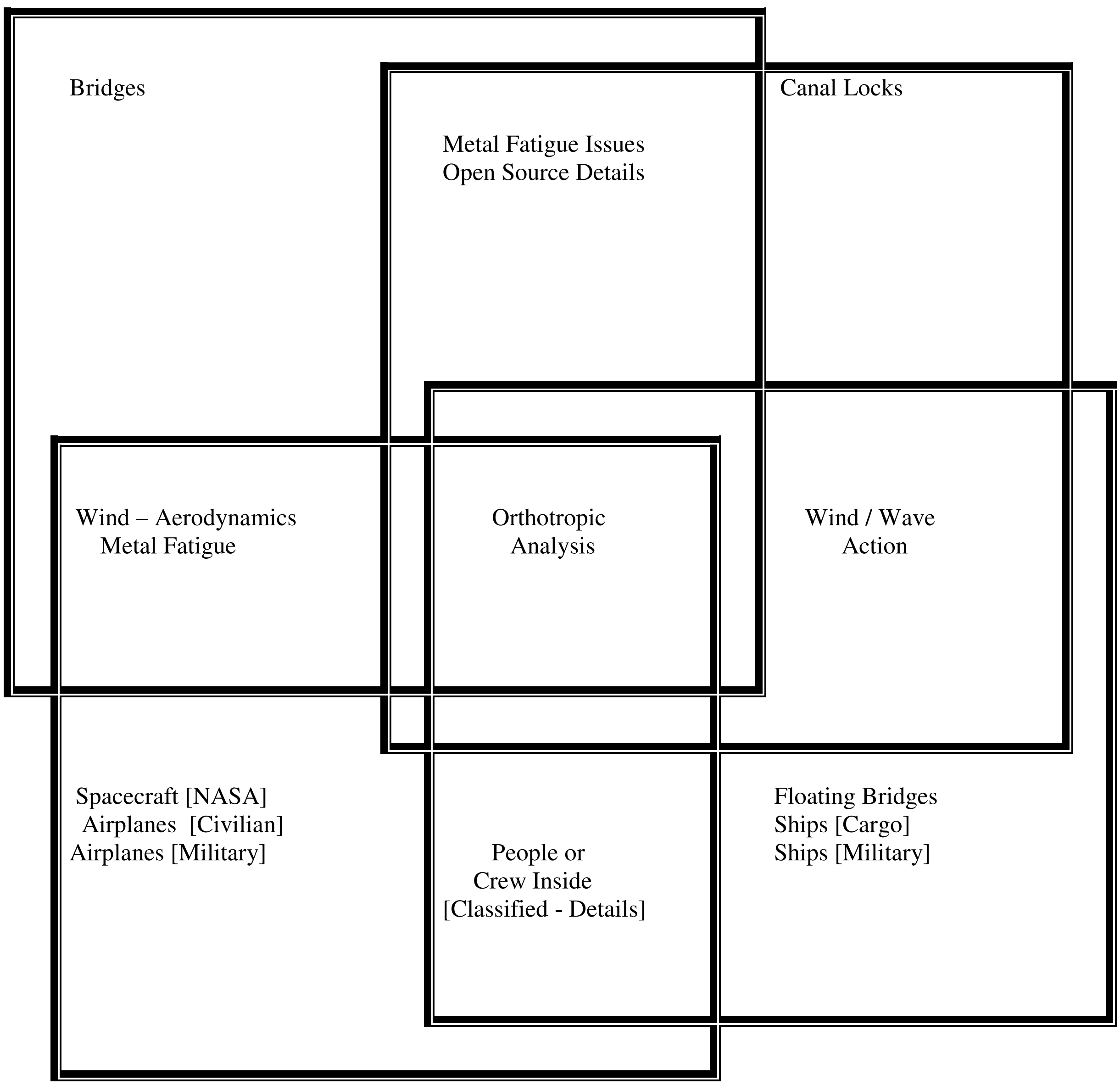
**Table 1: List of movable span bridges [ * riveted steel deck, not orthotropic] summary of Reference # 1 & 9.**

There is an under utilisation of the orthotropic steel deck superstructure because most efficient in terms of achieving the lowest total weight superstructure. A lower gross or dead load superstructure means less energy to move it. The lower dead load movable span results in smaller lifting cables, smaller trunnions, smaller motors, smaller towers etc. A lower dead load mass also means lower seismic forces on the structure during an earthquake. The Federal Highway Administration (FHWA) is advocating longer life for bridges in the USA. The examples selected demonstrate that steel orthotropic decks have been quietly doing their job of improving the transportation infrastructure of other countries. In Europe there are over 1,000 orthotropic steel deck bridges of all types.

# ORTHOTROPIC DETAIL CHOICES

## Development of the Orthotropic System

The origin and development of orthotropic steel deck bridges and similar objects occurred over many years and has many sources just like the roots of a tree [ see Figure # 5]. The Germans produced the first orthotropic bridge design manual in 1957. In 1963, the AISC funded and published the "Design Manual for Orthotropic Steel Plate Deck Bridges," authored by Roman Wolchuk (see Reference 3). The James F Lincoln Arc Welding Foundation has published M. S. Troitsky authored "Orthotropic Bridges" (see Reference 4). Both books are 40 years old with references from this time period. Newer references have been published (see Reference 2). It can be simplistic an idea that bridges are not related and no other evolving technology can help with the design of bridges. Civil Engineers were shocked when Tacoma Narrows Bridge blew down under a moderate wind in 1940. Improper aerodynamics caused the failure of the superstructure. Civil Engineers adopted existing wind tunnel equipment and methods for bridges immediately afterwards to analyze all bridges.

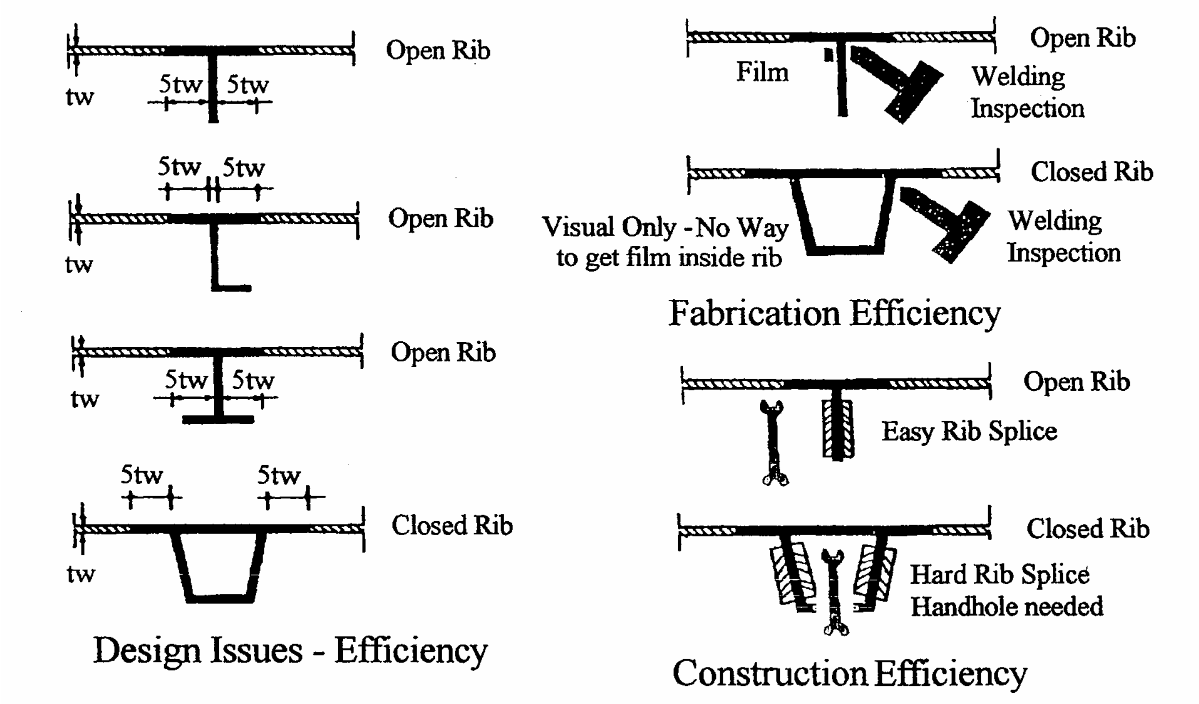



A graphic representation of interrelationships of objects utilizing orthotropic concepts and details[Figure # 5]

Civil Engineers have designed the longest span superstructures for box girders, arches, cable-stayed and suspension bridges using orthotropic steel deck system. Civil Engineers have adopted it for the largest movable bridges in many locations. However in Europe the largest percentages of movable spans of bridges are orthotropic steel deck. The other spans may be reinforced concrete deck, but the span requiring energy to move it, will be an orthotropic steel deck. Energy costs are much higher in Europe, but should you use extra energy in moving your span? Table 1 demonstrates a 50% weight savings by using orthotropic steel deck. An intimidating issue for the first time designer is the lack of readily available references, textbooks and software. No country or trade groups or government agency has current standard details for the orthotropic systems. So every bridge is currently a custom design with minimal resemblance to other structures.

| 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.<br>Not much dead weight savings |
| This table is based on one originally created and published by Dr. Thomas A. Fisher of HNTB Corporation | | | |

Table 2 Comparison of practical deck options for a 453-feet span by 55-feet wide movable lift span bridge.  Reference 1.




Selecting a rib system is really based on three issues: Structural, Fabrication and Construction Efficiency. [Figure # 6]

## Orthotropic Rib Choices

Thus the designer is left to mainly his or her own engineering abilities to complete a design. Unfortunately, only a few organizations design orthotropic steel deck bridges. The “catch-22” of research is that a “limited-use” deck system never warrants a global research effort. In spite of this fact some American engineers design orthotropic bridges for other countries, such as China.

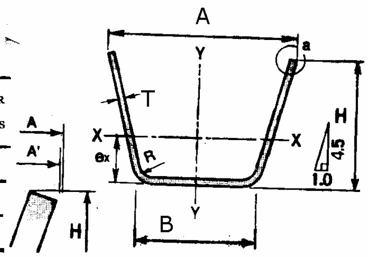
Experience in chosing the best rib or combinations is shown in Figure #6. Japanese researchers tried to tabulate trends in Japanese rib selections. Table 3 shows 44 rib shapes were selected for 257 different bridges.

| RIBS A × H × T | DIMENSIONS (mm) t | A | A' | B | H | R | AREA (cm²) | MASS (kg/m) | CENTROID $e_y$(cm) | INERTIA $I_x$(cm⁴) |
|---|---|---|---|---|---|---|---|---|---|---|
| 320 × 240 × 6.0 | 6 | 320 | 319.4 | 213.3 | 240 | 40 | 40.26 | 31.6 | 8.86 | 2460 |
| 320 × 260 × 6.0 | 6 | 320 | 319.4 | 204.4 | 260 | 40 | 42.19 | 33.1 | 9.91 | 3011 |
| 324.1 × 242 × 8.0 | 8 | 324.1 | 323.3 | 216.5 | 242 | 40 | 53.90 | 42.3 | 8.99 | 3315 |
| 324.1 × 262 × 8.0 | 8 | 324.1 | 323.3 | 207.7 | 262 | 40 | 56.47 | 44.3 | 10.03 | 4055 |

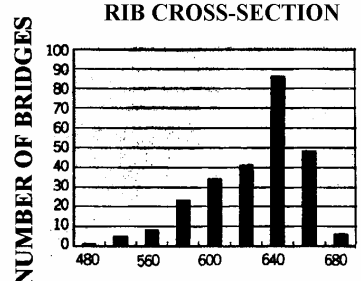
## TRAPEZOIDAL RIBS USED AS OF 1990

| RIB TYPE | DIMENSION (mm) WIDTH x DEPTH x THICK. | NUMBER OF BRIDGES | RIB TYPE | DIMENSION (mm) WIDTH x DEPTH x THICK. | NUMBER OF BRIDGES |
|---|---|---|---|---|---|
| 1 | 280 × 220 × 8 | 1 | 23 | 320 × 260 × 8 | 5 |
| 2 | 300 × 200 × 6 | 2 | 24 | 320 × 270 × 6 | 1 |
| 3 | 300 × 220 × 6 | 32 | 25 | 320 × 300 × 8 | 1 |
| 4 | 300 × 220 × 8 | 7 | 26 | 324.1 × 242 × 8 | 7 |
| 5 | 300 × 224.6 × 7.9 | 1 | 27 | 324.1 × 242 × 15 | 1 |
| 6 | 300 × 240 × 6 | 1 | 28 | 324.1 × 262 × 8 | 1 |
| 7 | 300 × 250 × 8 | 2 | 29 | 325 × 250 × 8 | 1 |
| 8 | 300 × 270 × 6 | 1 | 30 | 327.2 × 274 × 8 | 1 |
| 9 | 300 × 280 × 8 | 1 | 31 | 330 × 250 × 8 | 2 |
| 10 | 300 × 280 × 12 | 1 | 32 | 330 × 250 × 14 | 1 |
| 11 | 304.1 × 222 × 8 | 1 | 33 | 330 × 263 × 6 | 1 |
| 12 | 310 × 250 × 6 | 1 | 34 | 330 × 280 × 8 | 1 |
| 13 | 310 × 250 × 8 | 1 | 35 | 330 × 288 × 8 | 1 |
| 14 | 318 × 258 × 8 | 1 | 36 | 330 × 288 × 10 | 1 |
| 15 | 320 × 200 × 6 | 7 | 37 | 340 × 200 × 9 | 1 |
| 16 | 320 × 200 × 8 | 1 | 38 | 340 × 250 × 8 | 1 |
| 17 | 320 × 230 × 8 | 1 | 39 | 340 × 280 × 8 | 1 |
| 18 | 320 × 240 × 6 | 96 | 40 | 370 × 250 × 8 | 1 |
| 19 | 320 × 240 × 8 | 15 | 41* | 320 × 240 × 6 | 8 |
| 20 | 320 × 250 × 6 | 3 | 42* | 320 × 240 × 8 | 1 |
| 21 | 320 × 250 × 8 | 3 | 43* | 320 × 240 × 6 | 2 |
| 22 | 320 × 260 × 6 | 37 | 44* | 320 × 260 × 8 | 1 |

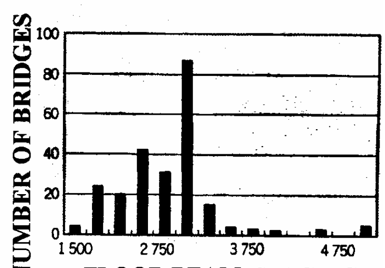
RIB CORNER RADIUS $R = 40$mm



RIB CROSS-SECTION



TRANSVERSE SPACING OF RIBS (mm)

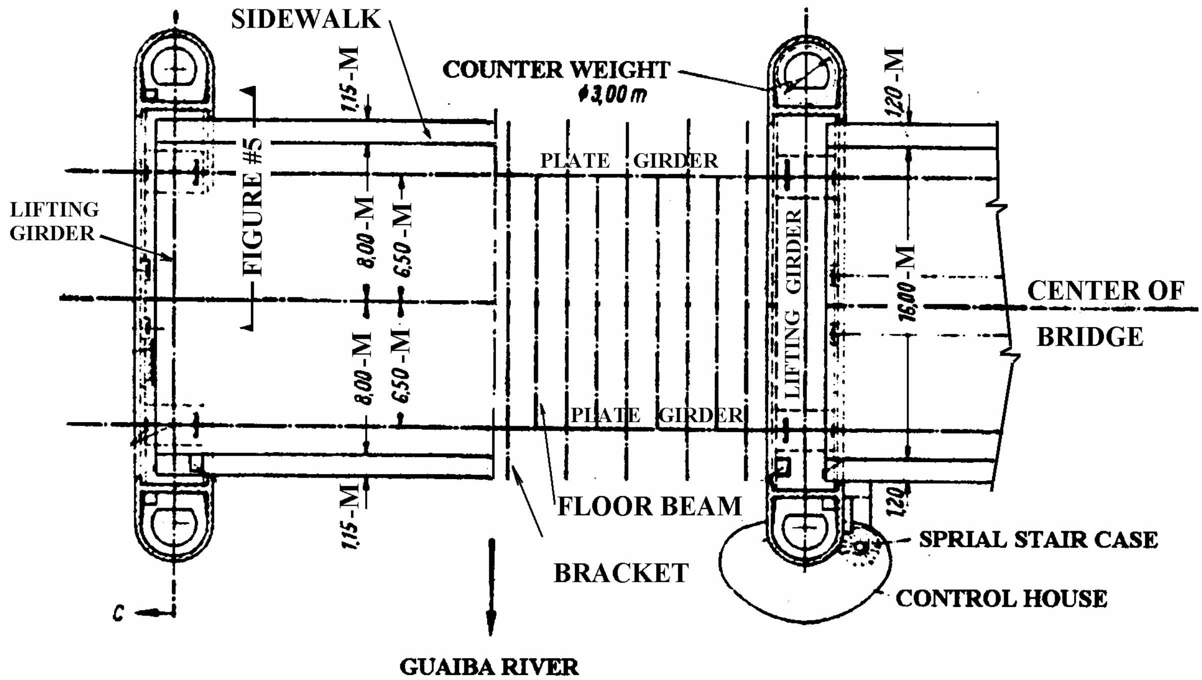


FLOOR BEAM SPACING in millameters

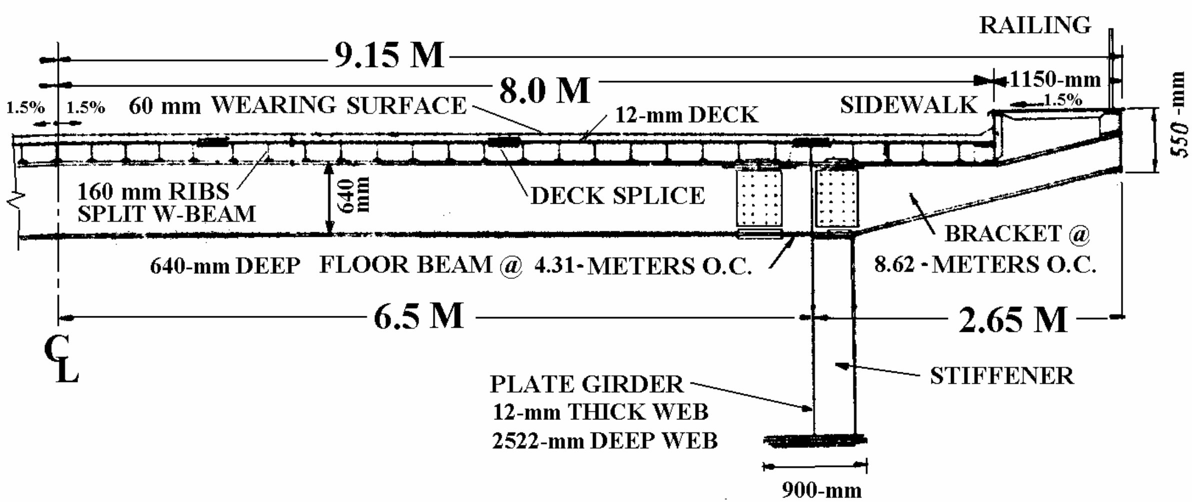
JAPANESE RIBS SURVEY OF 257 BRIDGESREPRINTED AND TRANSLATED FROM *ORTHOTROPIC STEEL DECKS* APPEARS IN "BRIDGES AND ROADS" OCT 1998 AND NOV 1999. BY MATSUI S.; OHTA K. AND NISHIKAWA K. OF PWR PUBLIC WORKS RESEARCH INSTITUTE [Figure # 3 ]

Table 3 Many Japanese standard trapezoidal rib are essentially identical to Bethlehem Steel ribs and Germany's Krupp Steel shown in tables in Reference 2.

## Guaiba Bridge at Porto Alegre, Brazil




GUAIBA BRIDGE 180 FT SPAN GUABIA VERTICAL LIFT Designed by FRITZ LEONHARDT. Adapted from Die Guaiba Bruke bei Porto Alegre Brasilien Beton- und Stahlbeton 58 (1963) pp. 273-279 [Figure # 7]




GUAIBA BRIDGE with an 180 FT SPAN GUABIA VERTICAL LIFT BRIDGE BRAZIL Designed by FRITZ LEONHARDT. Adapted from Die Guaiba Bruke bei Porto Alegre Brasilien Beton- und Stahlbeton 58 (1963) pp. 273-279 [ Figure # 8 ]

Dr. Fritz Leonhardt, a former Autobahn engineer, designed a large lift span in South America with a true orthotropic deck (see Figures #7 & 8 and Reference # 5). The Guaiba Bridge at Porto Alegre, Brazil has four plate girders around the perimeter of the orthotropic steel deck lift span of 183-feet (55.8 meters) by 60-ft (18.3-m). This four-tower bridge was completed in 1960. On each side of the deck are 8.28-ft deep girders that have 160-mm deep split w-beam "open rib" on top. Steel plates were used for the vehicular deck and the sidewalks. The lifting girders are two slightly larger plate girders. This allowed standard bolted splice plates to be utilized throughout the deck. The straightforward design has the repetition that engineers prefer. A recent inspection and sheave repair showed that the orthotropic steel deck was working properly (see Reference # 6).

# LIFT BRIDGES

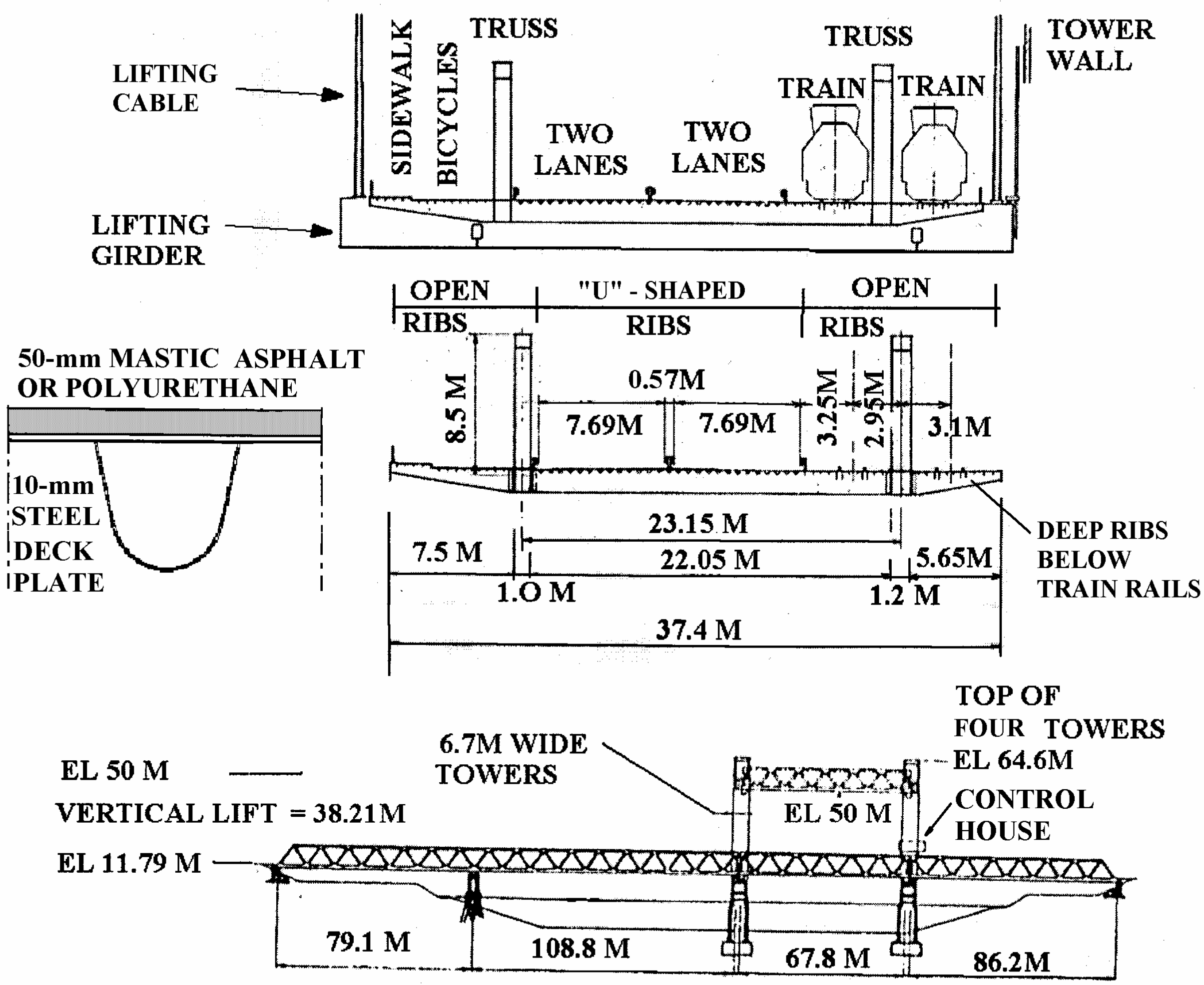
## Danziger

AFTER HURRICANE KATRINA, AERIAL PHOTO OF 320 FT SPAN DANZIGER VERTICAL LIFT BRIDGE NEW ORLEANS
Designed by Jacobs -Sverdrup Civil, Inc. Photo Courtesy of Kian Yap PE of Louisiana DOT. AISC PRIZE BRIDGE [FIGURE # 9]

The Industrial Canal Bridge or Danziger of New Orleans, AISC Prize Bridge was described in the year 2000 paper. This bridge is four times the deck area of the Guaiba Bridge, and survived undamaged (see Reference # 7).

## Caland Bridge

In 1969, a lift span bridge was built in Rotterdam Netherlands [see Figure 10]. Warren trusses built of steel box sections are the main component of the orthotropic steel deck lift span of 223-feet (67.8 meters) by 123-ft (37.4-m). The transverse floor beam has the same depth as the truss bottom chord. The lifting girders are substantially deeper, supported by cables from four lifting towers. The lift span has train, vehicular, bicycle and pedestrian traffic. Below the vehicular traffic are U-shaped ribs. Open ribs are used in other locations. Large stiffeners are located below the train rails. The bridge is described in Reference # 10. The lift span has four vehicular lanes, two railroad tracks, a bicycle path and a sidewalk for pedestrians. The superstructure cross-section consists of a 10-mm steel deck with trapezoidal stiffeners. The original surfacing system was based on bitumen binders (mastic asphalt). Part of the wearing surface has been replaced on polyurethane resins and both the original and replacement had a thickness of 50-mm. The Caland Bridge has been extensively monitored with strain gages (see Reference # 9).

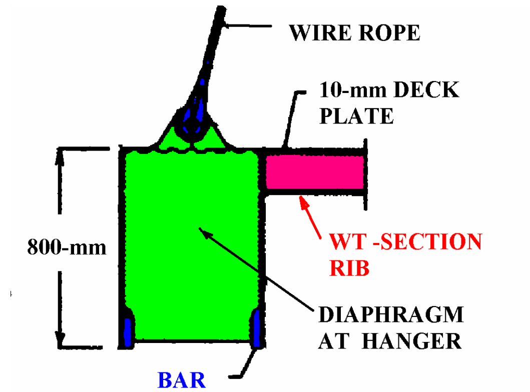



CALAND LIFT BRIDGE, ROTTERDAM, NETHERLANDS Image Courtesy of Henk Kolstein of the Delft[ Figure # 10]

## Lowry Center Bridge

An orthotropic steel deck lift span of 183-feet (55.8 meters) was completed in 1999 [see Figures 9and10]. A special barge was brought to the United Kingdom from France to ship this footbridge into position in Manchester. The 250-ton steel lifting bridge will link the city's proposed Imperial War Museum North with the new Lowry Center, currently being built on the opposite side of the Manchester Ship Canal. The bridge has a main span of 91 m and is a steel tied arch structure designed by consultant Carlos Fernandez Casado of Spain and Parkman of the United Kingdom. Four tubular steel frame towers support the lifting sheaves 32-m above the sides of the canal. Hydraulic motors, in machine rooms, at each abutment, power the lifting mechanism. The prime contractor for the $7.5 million [U.S. dollars] orthotropic steel deck "basket-handle" bridge was Christiani & Nielsen who coordinated the installation operation with freight transport specialist Econofreight. The basket-handle bridge lift span was first moved from the steel fabrication yard onto a 60-m long barge using hydraulic jacks and two hydraulically operated transporter units. The one-piece span was then towed along the Manchester Ship canal to the bridge site. Next it was attached to the shore with cables. Winches were used to place it between the four tubular steel frames.

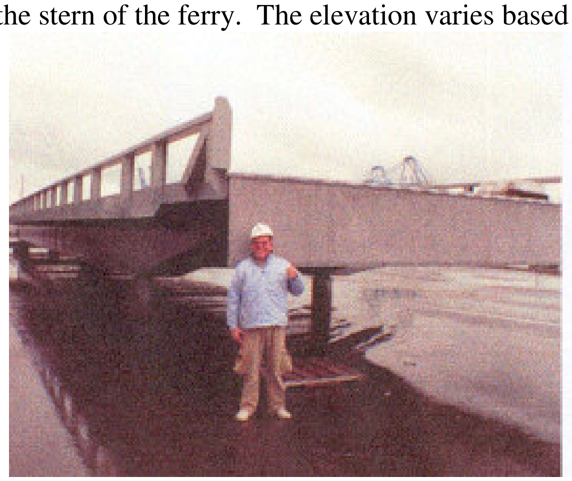
LOWRY CENTER PEDESTRIAN BRIDGE Photo Courtesy of Carlos Fernandez Casado [ Figure # 11 ]



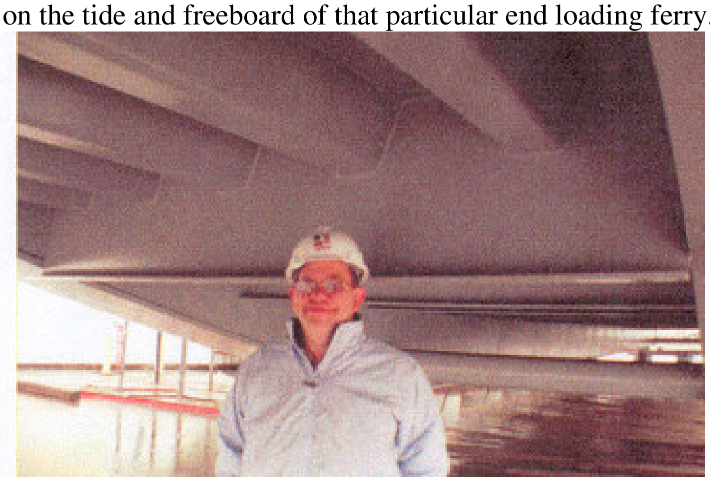

LOWRY CENTER PEDESTRIAN BRIDGE – DETAIL OF ARCH BOX CHORD ORTHOTROPIC STEEL FLOOR DECK & RIBS [ Figure # 12 ]

## Washington State Ferry Terminal and other Ferry Terminal Ramps

Three articulating ferry terminal ramps were designed for the State of Washington Ferry system located in three different sites (see Figures 12-13). Bainbridge Island was one location. Berger / ABAM Engineers of Federal Way, WA designed the 24-foot wide by 91-foot long all steel ramps. The one end of the ramp hinges on the end of a fixed abutment. Two counter-weight towers are used to adjust the ramp to the deck level at the stern of the ferry. The elevation varies based on the tide and freeboard of that particular end loading ferry.



Alaska Ferry Ramp Photo Courtesy of Jessie Engineering [Figure # 13]



Author Below Ramp Photo by Bill Dougherty of Jessie Engineering [Figure # 14]

This architecture is also common for ferries terminals located in British Columbia and the state of Alaska. The counterweights are enclosed to protect them from freezing water and snow. There is about a twelve-foot tide. Their engineers selected a rectangular rib 9.75 inches x 12.375 inches deep with spacing pattern of 18 inches (see Reference # 45 ). The author was photographed standing below an orthotropic steel deck ramp ready to be shipped to Alaska, July 2006 at the Port of Tacoma, WA[Figures # 13 & # 14]

## U.S. Navy Orthotropic Floating Dock

Nicolas Island, California floating dock was built as barge or pontoon shapes for the US Navy. This was a design build by the NOVA Group with Engineer of Record Winzler and Kelly Engineers of San Francisco. Pontoons are 52.995-M x 6.7250-M. Rectangular Ribs were used on all internal sides of pontoon exterior surface plates. Ribs on driving surface were spaced at 560-mm. Floor beams are 306-mm deep x 64-mm wide bent plates. Diagonal trussed braces are WT 100 x 11 [metric]

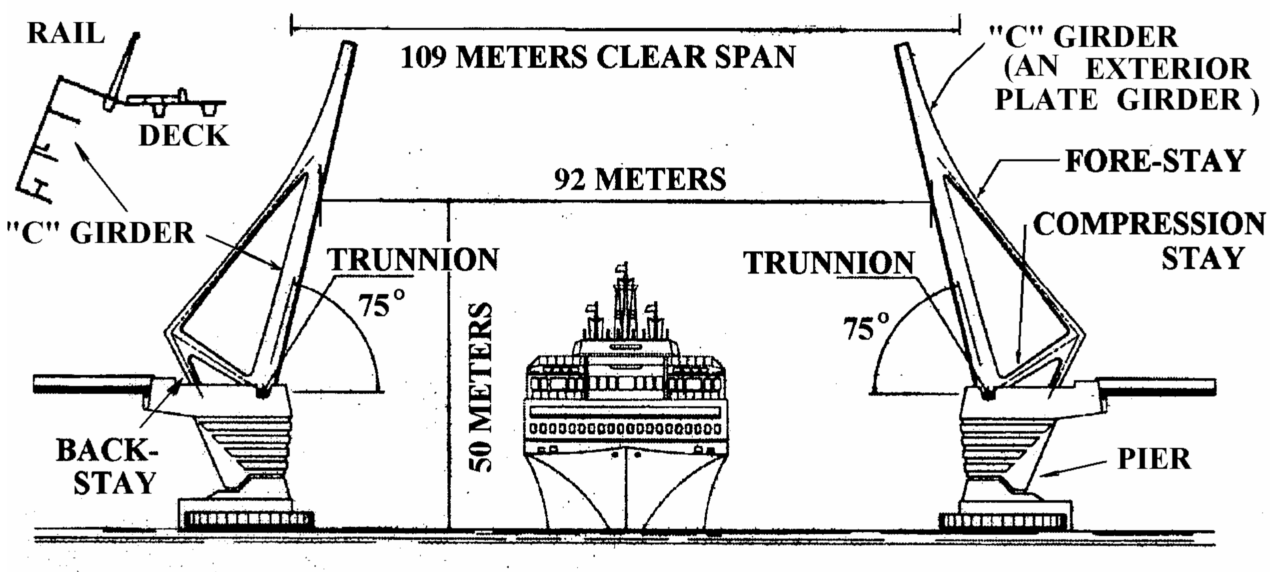
Nicolas Island, California floating dock Photo Courtesy of NOVA Group [Figure # 15]

Nicolas Island, California floating dock Photo Courtesy of NOVA Group [Figure # 16]

## Bascule Bridges

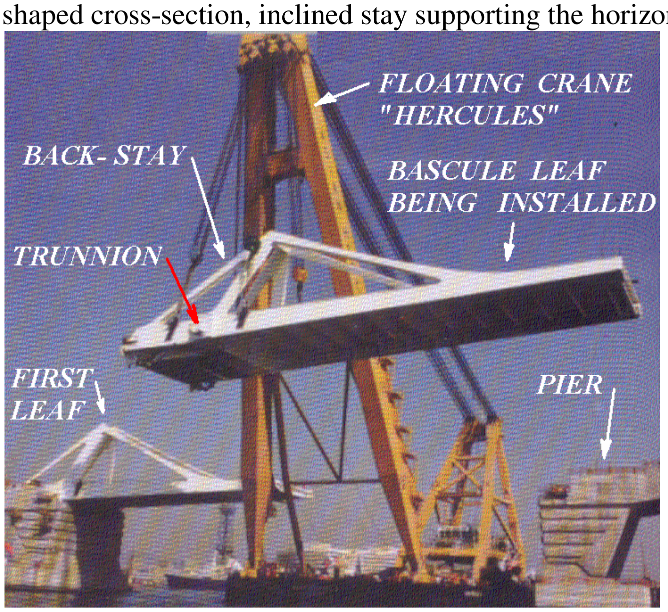
## Porta d'Europe Double Bascule Bridge

A double bascule Bridge (The Gate of Europe) for the Harbour of Barcelona was completed in July 2000 for a total cost $16 million (U.S. dollars). The Barcelona Port Authority decided to open a new harbour entrance, crossing the existing jetty facing the Mediterranean Sea. Structural Design and Construction Supervision was Dr. Juan José Arenas de Pablo of Santander Arenas y Asociados S.A., Santander, Spain. The contracting joint venture of the Spanish firms FCC (Fomento de Construcciones y Contratas), FCC Construcción, and Contratas Javier Guinovart built the "La Porta d' Europa" Bridge. Barcelona Port Authority held a contest for the design and construction of a movable bridge. A maximum horizontal clearance of 92-m with 50-m vertical clearance was provided. Two approach viaducts of some 300 m length with a 6.5% slope were to be built, situating the double bascule orthotropic bridge at a height of 22 m above water level and allowing smaller ships to pass underneath the closed bridge. The movable spans are a double bascule bridge with two leaves. This is a stayed bridge with steel frames and stays above the roadway. The trunnions of the bridge are 109-m. In order to accommodate the counterbalances, each bascule leaf extends 14-m from the trunnion to its rear end, resulting in a total length of the movable span of 137-m. In the open position, at a maximum rotation of 75 degrees with respect to the horizontal, the tips of the rotating sheets are about 74-m above water level (see Figure #17 and Reference # 11). The opening of the white painted bascule leaves with a deep blue sky demonstrates the beneficial effect of the continuous interaction of functional and aesthetic considerations throughout the design process (see Figure # 18 & #19). There is a horizontal clearance of 92-m at a height of 50 m above water level. The bascule leaves have been derived from a typical rectangular-shaped cross-section.

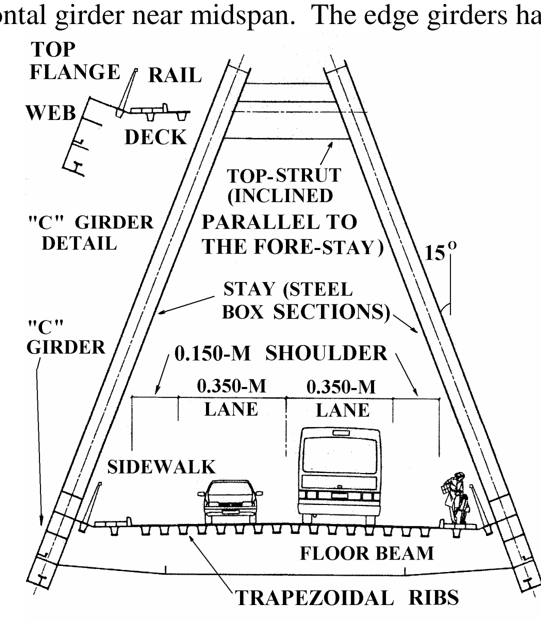


PORT OF EUROPE DOUBLE BASCULE BRIDGE courtesy of IABSE & Dr. Juan José Arenas de Pablo, Arenas & Asociados, S.L., Santander, Spain. [Figure # 17]

However, the webs have been laterally inclined and are situated at the long edges of the deck, (see Figure # 19). The 12-m wide orthotropic steel deck is supported by transverse floor beams space about 4.2-m on centre. These beams are, in turn, supported by two lateral steel frames or stays inclined at about 15° to the vertical plane and they rise 15-m above the deck. Each of these stay frames consists of a horizontal edge girder running along the outside of the deck, a triangle composed of a compression pylon and an end backstay, and a unique steel stay supporting the horizontal girder near midspan. The edge girders have a C-shaped cross-section, inclined stay supporting the horizontal girder near midspan. The edge girders have a C-



PORT OF EUROPE DOUBLE BASCULE BRIDGE courtesy of IABSE & Dr. Juan José Arenas de Pablo, Arenas & Asociados, S.L., Santander, Spain [Figure # 18]

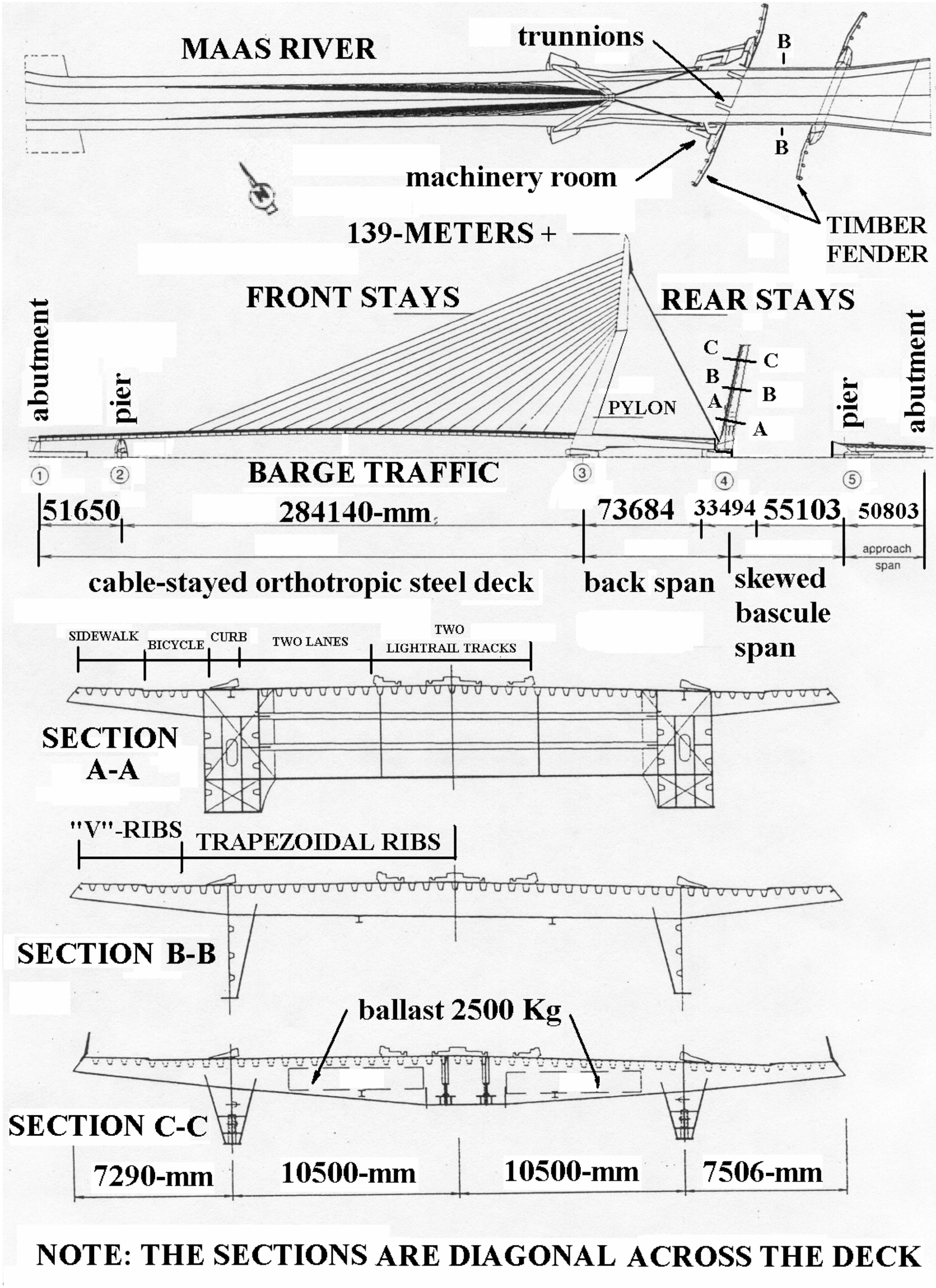


PORT OF EUROPE DOUBLE BASCULE BRIDGE CROSS-SECTION courtesy of IABSE & Dr. Juan José Arenas de Pablo, Arenas & Asociados, S.L., Santander, Spain [Figure # 19]

shaped cross-section, with inclined webs constituting the outer planes of the superstructure, adopting the inclination of the frames. Their depth varies linearly between 1.84 m at midspan and 4.16 m at the rear end, corresponding to a depth of 3.68 m at the rotating hinges. The compression pylon, the end backstay and the steel stay are all made from 0.75-m wide hollow-box cross-sections of variable depth. The counterweight is defined by the condition that the centre of gravity of dead weight and permanent load of each leaf must coincide with the axis of the trunnion. Thus, when rotating the leaves, the resultant of these vertical loads will always pass through the axis of the trunnion, and the hydraulic devices merely have to resist friction and wind forces. The counterweight, made from reinforced concrete, is located underneath the rear part of the deck and has been calibrated before installation of the bascule leaves in order to account for construction tolerances. In their open and closed position, the bascule leaves are supported by the trunnions and by lock-down devices at their rear end, which transmit their reactions to the rear transverse girders of the main piers. These rear supports have to resist both positive and negative reactions, depending on the position of superimposed loads and the direction of the outer in the transverse box beam connecting the heads of both stay frames. The planes of the superstructure were laterally inclined at about 15° to the vertical plane two reasons. First, from an aesthetic point of view, inclining a plane such that the deck width increases from top to bottom results in a much better orientation for sun lighting, helping to produce a bright border cornice in the bridge. Second, there is an increase in stiffness similar to a basket handle arch. Closed ribs were used for the bridge deck.

## Erasmus Bridge

The Public Works Department of the city of Rotterdam, Netherlands is the owner and operator of the Erasmus Bridge (see Figure # 20). The construction of the Erasmus Bridge in the harbor area of Rotterdam, for which architect Ben van Berkel made the original design in 1989, construction began in 1994 and was finished in the fall 1996. Van Berkel & Bos was the lead consultant for the Department of Works of Rotterdam. The main contractors were Heerema Vlissingen; Grootint Dordrecht and Ravenstein Deest. The unique 139-m. tall pylon for the cable-stayed span, and has a movable bascule section that permits the passage of ships taller than the Rhine River navigation height. The tower and bascule machine rooms are located downstream in the shallows adjacent to an island, so this unique shape does not impede river traffic. "The Swan" Bridge has two light rail tracks, 4 lanes of vehicular traffic; 2 bicycle lanes; and 2 sidewalks with the river walk. The single leaf orthotropic bascule is one of the largest in the world, with a deck measuring 172-ft by 117-ft (52.3 by 35.8-m), and an apron weighing 3.5 million lbs. (1,560-metric tons). In an open position, the fall stands 62-ft (19-m) "out of plumb." The bascule column has three functions: first, the anchoring of the cables of the "rear-stays" from the pylon of the bridge; second, it provides the foundation for the trunnions of the Bascule Bridge; and third it houses the bascule pit and mechanical equipment room. The 0.7-in (18-mm) thick orthotropic steel bridge deck is reinforced with trapezoidal stiffeners measuring 24-in (600-mm) center-to-center. The fully welded deck has a 0.3-in (8-mm) thick synthetic resin wearing-surface, providing considerable savings on the structure's dead weight, compared to an asphalt mastic-wearing surface. The deck plate, box-shaped longitudinal girders, cross, and main girders form a fully welded, orthotropic steel bridge. The cross girders and consoles were fabricated in the form of girder plates. Girders are box profiles around the rotation point, where bending and torsion moments are greatest. The box girders absorb the large torque and bending load with a minimum of distortion. At the 2/3 front end of the bascule deck cantilever, the forces and required rigidity are less, and the cross section transitions a girder plate of the same depth as the box section. To limit the diagonal eccentricity of the deck, the sideward twist was placed in front of the main rotation point wherever possible. The weight of the Bascule Bridge was almost completely balanced by the counterweight, except for the front bearing pressure. The ballast was located eccentrically in a diagonal direction to compensate for the obliqueness of the bridge. This equally distributes both the weight responses in the main rotation points, and the bending moments caused by the bridge's own weight in both main girders. The moving time is limited to 120 seconds for the opening and 135 seconds for the closing of the bridge (see References # 12 to # 15)



"The Bascule Bridge of the Erasmus Bridge, Rotterdam" Reusink, J. H. courtesy of Bouwen met Staal [ Figure # 20 ]

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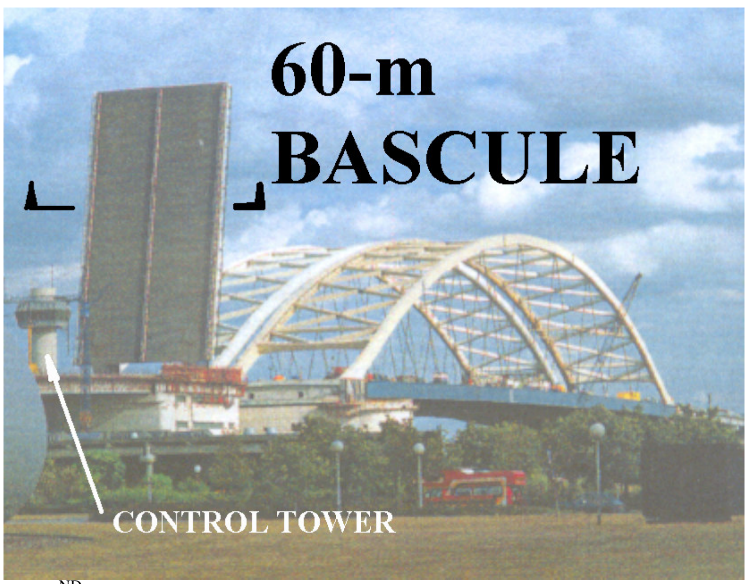
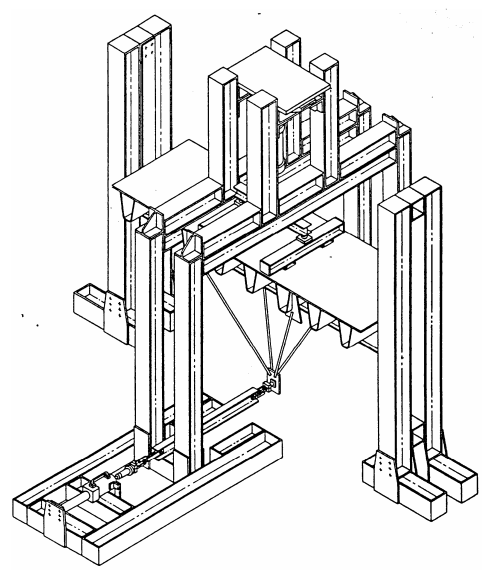
## Van Brienenoord Bascule Bridge

The Van Brienenoord parallel bridges were completed in 1958 and 1990 in the harbor area of Rotterdam, Netherlands (see References # 16 & # 19). The owner/operator of the bridges is the Rijkswaterstaat, the Department of Public Works of the Netherlands. The A-16 freeway crosses the Nieuwe Mass River using these bridges. Each bridge has a main span of a tied arch, but detailing is different. The 1958 bridge has an open rib orthotropic steel deck, while the 1990 version uses closed ribs (trapezoidal) suspended by inclined cables from the arch. At the side of each tied arch is a single leaf bascule bridge. Plate girders are used for the main beams and transverse floor beams for the bascule. The length of the 1990 bascule span is 60.24-m and a width of 27-m [six traffic lanes] and has a weight (including ballast) of 1670 metric tons. A single control tower operates both parallel bascule bridges. The largest number of orthotropic bridges is in Europe. Since 1997 in several heavily loaded highway bridges in the Netherlands, fatigue cracks were observed in the welded connection between the longitudinal trapezoidal stiffener web and the deck plate of the orthotropic




The 2ND parraellel Van Brienenoord Bascule Bridge courtesy of Henk Kolstein See reference # 16 [ FIGURE # 21 ]



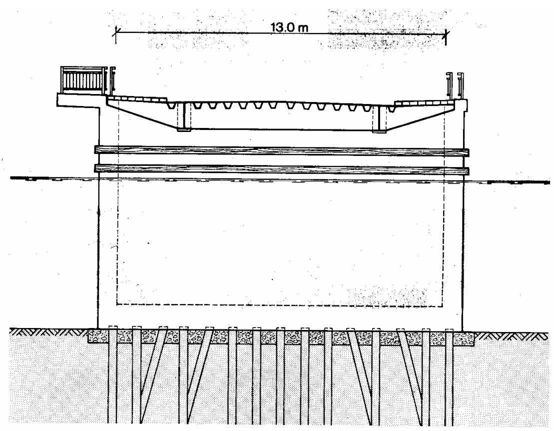
DECK TESTING AT DELFT, NETHERLANDS
Kolstein, M. H., and J. Warendier,
See reference # 19 [FIGURE # 22 ]

bridge deck. Depending on the crack initiation point they could be found and repaired relatively easily. In some cases, cracks are relatively large and their repair is difficult. Some fatigue cracks propagate through the deck plate and the wearing surface and grow in longitudinal direction parallel to the deck plate weld. This type of crack has been found in this bascule bridge deck and another thirty-year-old bridge deck. One longitudinal crack of 800 mm was found. Both steel decks are 12-mm thick on the movable bridges, surfaced with a relative thin wearing course of about 8-mm thickness. The trapezoidal stiffeners cannot be observed during regular inspection from underneath the bridge deck. German steel company ribs were used on the bridge. The long adjacent parallel cracks could cause a deep deflection of the deck plate above the longitudinal trapezoidal ribs. Therefore repairs were completed by grinding and filling the grooves with butt welds. The dimensions of the rib are the German steel company "Krupp FHK 2/325/6" with a structural height of 325 mm, a base distance between the outside face of the trapezoidal legs of 300 mm, bottom width of 105 mm and a plate thickness of 6 mm (300 x 325 x 6). The plate thickness of the crossbeam web support of the continuous longitudinal stiffener is 10 mm. The surfacing on fixed bridges thick wearing surfacing of

40 to 80 mm. The number of trucks in the heaviest loaded lane on this bridge was about 7,000 trucks per day in 1997. Both bridges remain in operation.

## Various small Bascule Bridges

There are probably 30 to 50 small bascule bridges completion in Europe The Stenke Bridge in Denmark is a typical example. The navigation span is 11.5-m with a wider width of 13-M to have 2-lanes of Traffic and 2-M sidewalks on each side. The other spans of 22.8-M and 221.2-M are prestressed concrete the bridge was designed by COWI and completed in 1980. Another larger bridge at Kosør Denmark is a Strauss Bascule Span of 29-M steel deck orthotropic deck [Figure # 2] and opened to traffic in 1985. The 21-M wide bridge carries two vehicular lanes of total width of 9-M. Also carried by the two steel warren trusses are railway tracks and sidewalks. 600-MetricTon hydraulic jacks are used to open the span. The remaining spans are prestressed concrete girders. Another small bascule span is located in Canada [Figure #3]

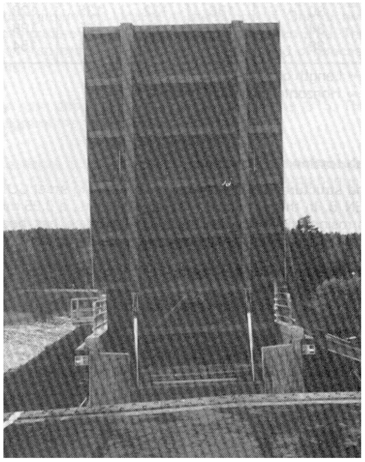



SECTION OF STEKE BASCULE BRIDGE, DENMARK Designed by COWI Civil, Inc. Drawing Courtesy of COWI [ FIGURE # 23 ]

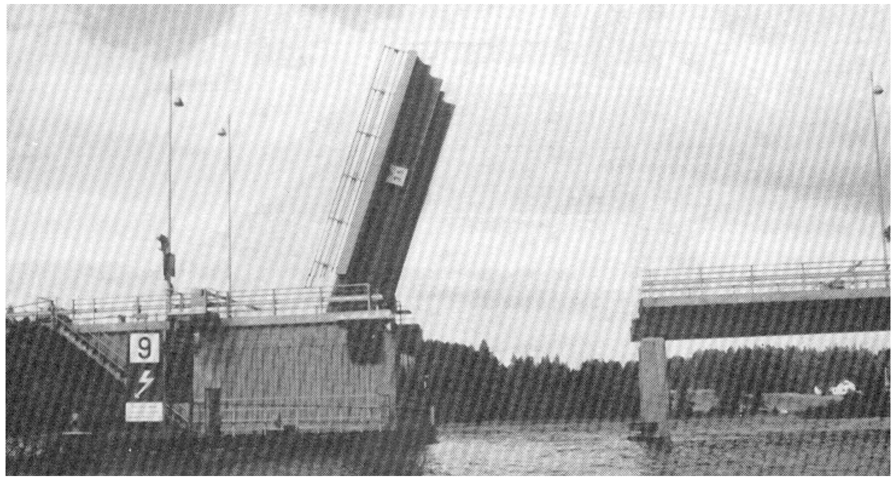
STEKE BASCULE BRIDGE, DENMARK Designed by COWI Civil, Inc. Photo Courtesy of COWI [ FIGURE # 24 ]

## The Kellosalmi Bascule Bridge, Finland

The Kellosalmi bridge, completed in 1987 is owned by the Finnish Roads and Waterways Administration (RWA.). The contractor was Insinooritoimisto Syviirakenne ay and the Consulting Engineers are Insinooritoimisto Pontek Ky. The construction work had duration of about 11 months. This bridge is one of three movable bridges, for where opening and closing are controlled by an automatically operated system. The boat captain starts operation of the bridge's system. This bridge does not require any operating personnel. There are maintenance employees trained to Service and respond to any operating failures. Failure alarms are automatically sent to the maintenance firm by a telephone-robot. The bridge consists of two parts a movable single-leaf bascule orthotropic steel bridge and a two-span fixed bridge. The fixed part is a composite girder bridge with a reinforced concrete deck. Its spans are 24 m + 18 m. The leaf spans 12.0 m. The horizontal navigation clearance is 8.6 m, and the clear headway 3.5 m. The orthotropic span is a grid structure with two main steel girders. Transverse girders at center-to-center at 2 m. and a deck plate with longitudinal stiffeners. The forward end of the leaf rests on an elastomeric pad- bearing and at the abutment end it is supported by two fixed spherical trunnions (steel spherical sliding bearings). In addition to the trunnions, the leaf is in the opening and closing stage, is supported by hydraulic cylinders at each main girder. The maximum opening angle is 81 degrees. A hydraulic drive unit run by an electric motor supplies the operating force for the cylinder. During the sailing season, the temperature of the hydraulic oil is kept at or above a minimum of +20°C by a heater equipped with a thermostat.



DETAIL of KELLOSALMI BASCULE BRIDGE, PASDASJOKI, FINLAND Photo Courtesy of IABSE. [ FIGURE # 25]



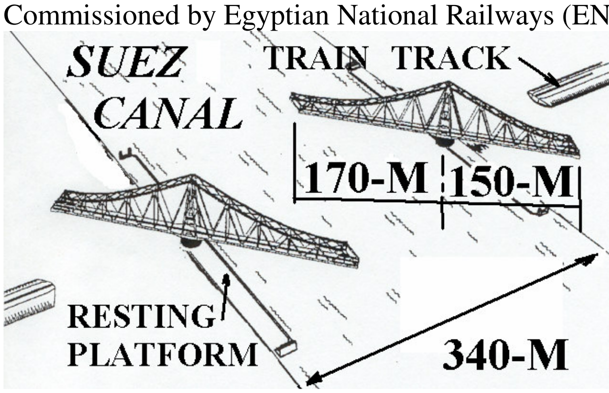


KELLOSALMI BASCULE BRIDGE, PASDASJOKI, FINLAND Photo Courtesy of IABSE. [ FIGURE # 26] –refernce IABSE Structures C-44/88 "Structures in Finland" pp 14 & 15

# Swing Bridges

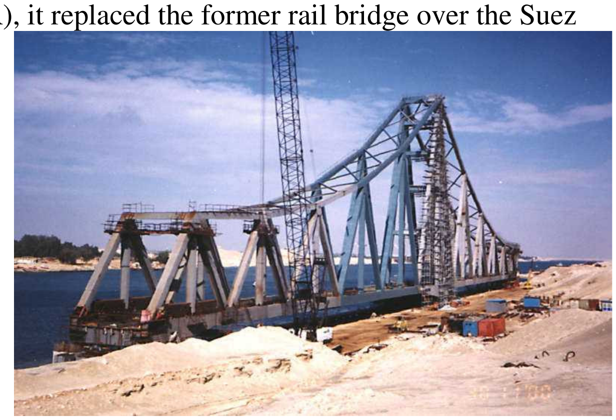
## El Ferdan Bridge

The longest span swing bridge in the world is nearing completion in Egypt at El Ferdan, near Ismailia. The contract value of this steel deck orthotropic deck double swing truss bridge is about $ 70 million U.S. dollars. Total steel tonnage is 10,500 tons and bridge is planned to open in late 2001 (see Figures 29-30). Commissioned by Egyptian National Railways (ENR), it replaced the former rail bridge over the Suez



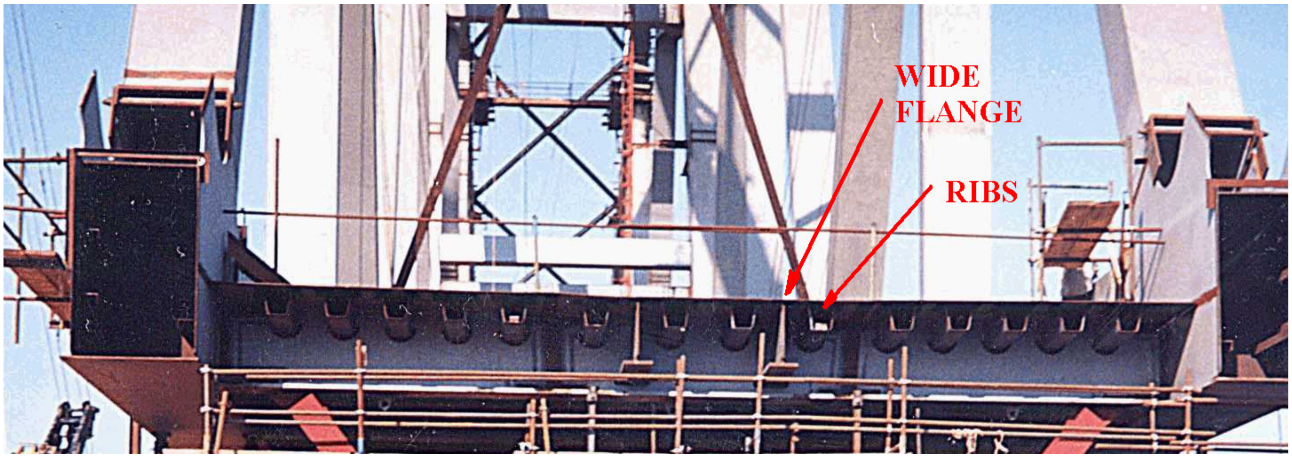


EL FERDAN double swing bridge Schematic courtesy of Tomlinson, G K ; Weyer, U.; Maertens, L.;Binder B. "El Ferdan Bridge – design" Bridge Engineering Conference, March 2000 - Sharm El Sheikh, Sinai, Egypt [ Figure # 27]



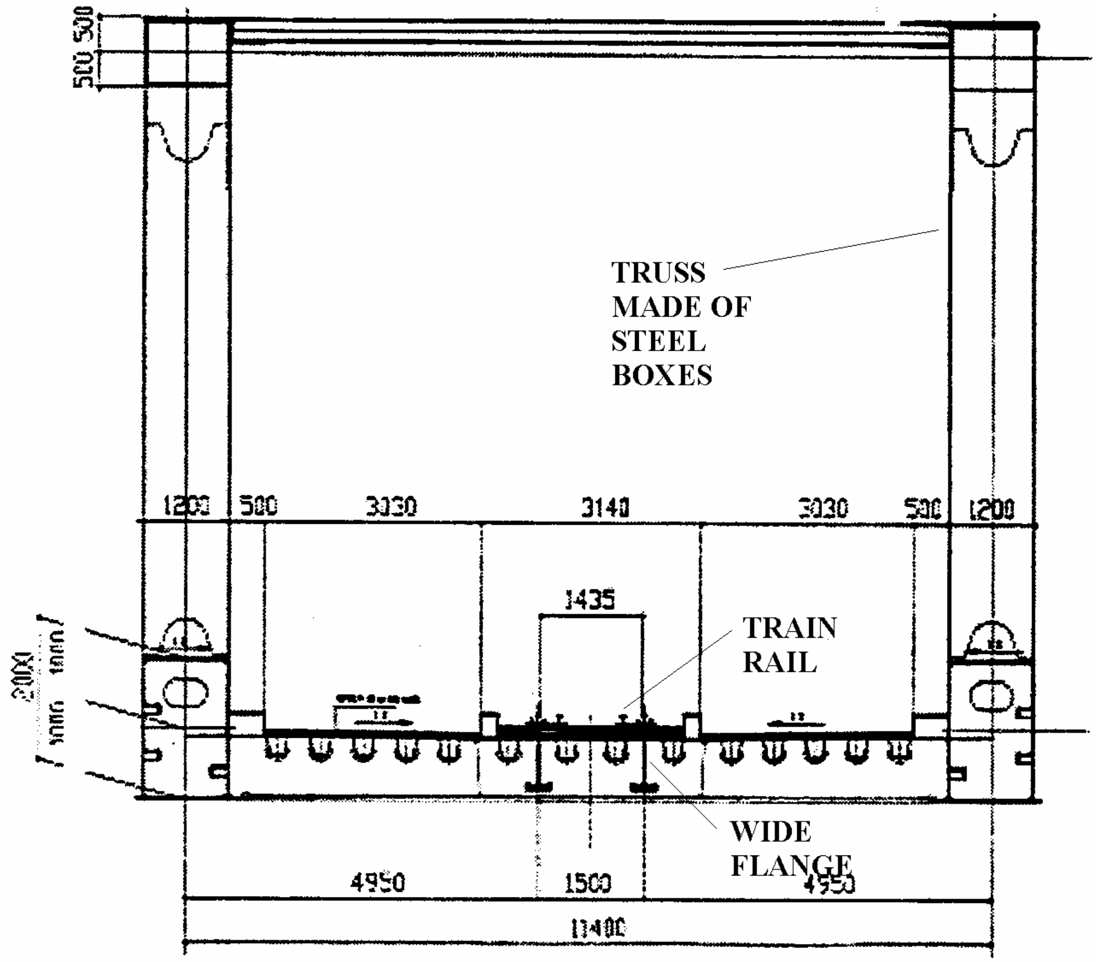
EL FERDAN truss under construction with crawler crane on banks of the Suez Canal 2001. Photo courtesy and by Nick Fuchs PE of Halcrow Group Limited & Egyptian National Railways. [ Figure # 28]

Canal, which linked Cairo to the Sinai until 1967. The Suez Canal continues to be one of the world's most important man-made shipping channels and is a vital contributor to the economy of Egypt. At the site of the new El Ferdan Bridge, 14-km north of Ismailia, the canal has recently been dredged to a depth of 27 meters and its width increased to 320 meters. Egyptian National Railways retained the United Kingdom consultant-engineering firm of Halcrow Group Limited to be the Technical Advisor in May 1996. Halcrow performed the technical evaluation of the bids, review of the contractor's design and finally supervision of the construction of this orthotropic bridge. The design and build contract was awarded to Consortium El-Ferdan Bridge comprising Krupp Stahlbau and Krupp Fördertechnik of Germany, Besix of Belgium and Orascom of Egypt in July 1996. The new bridge will be the fifth to be constructed at this location and will enable the existing rail infrastructure




EL FERDAN orthotropic deck details under construction on bank of Suez Canal Egypt in 2001. Pipe scafolding provides access for the workers. Photo courtesy and by Nick Fuchs PE of Halcrow Group Limited [ Figure # 29 ]

links between Cairo and the Mediterranean ports on the West Bank of the Canal to be restored and extended into the Sinai. A tunnel alternative was also considered but the required depth of the tunnel together with the limitation on approach gradients would require long approaches, and result in a much more expensive crossing. A schematic design was prepared for a double-cantilever steel truss girder swing bridge and bids were received from four international design-build contracting groups The structure comprises a double cantilever swing bridge with pile supported concrete foundations for the pivot piers supporting a steel truss superstructure (see Figure # 27). The main span is 340-m and when closed has an overall length of 640-m. The 12.6-m wide truss is 60-m high at the pivot reducing to 15-m at mid-span and the orthotropic steel deck carries a single railway track and two road lanes. Over 15,000 ships pass through the canal each year carrying 14% of world trade. Design was in accordance with Egyptian, German and U.K. standards with equivalent national standards substituted where necessary. Design issues considered included canal bank stability, aerodynamics, both of the whole structure and individual members, seismic analysis, load distribution in the rim bearing, and fatigue effects on the rollers. Of the 10,500 tons of fabricated structural steel used in the structure, some 4,000 tons have been fabricated in Germany, with the remainder fabricated in Egypt in accordance with international quality control procedures. The truss is fully welded with pre-assembly carried out on both east and west banks. As the bridge is a swing bridge it is erected parallel to the canal bank using crawler cranes. During erection the bridge is supported on temporary supports at the pivot pier locations and erection proceeds in accordance with the balanced cantilever method. A temporary transverse support is provided to resist wind effects. Once each bridge is completed including surfacing trial rotations will occur including adjustment of level at the central joint. Only then can the final approach works, abutments and locking heads can be completed. The orthotropic superstructure utilizes three rib types. A trapezoidal section can be seen for most of the deck section. Large split–wide flanges are welded directly below the rails supporting a single rail line. Finally, angles are used as horizontal stiffeners for the box members for the steel truss (see Figure# 29 and References # 17 and # 18).

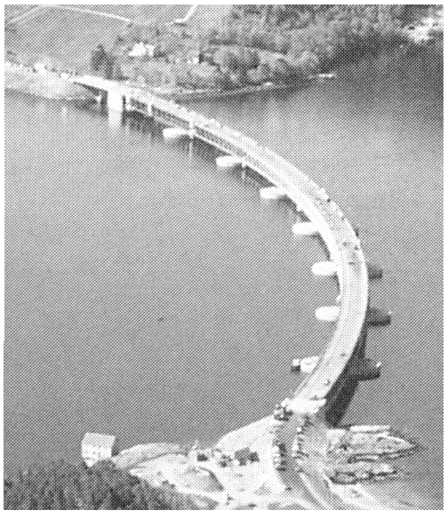



EL FERDAN orthotropic deck details under construction on bank of Suez Canal Egypt in 2001. Pipe scafolding provides access for the workers. Drawing [dimensions in millameters] courtesy and by Nick Fuchs PE of Halcrow Group Limited [ Figure # 30 ]

# FLOATING BRIDGES

## Bergøysund Floating Orthotropic Steel Deck Bridge of Norway

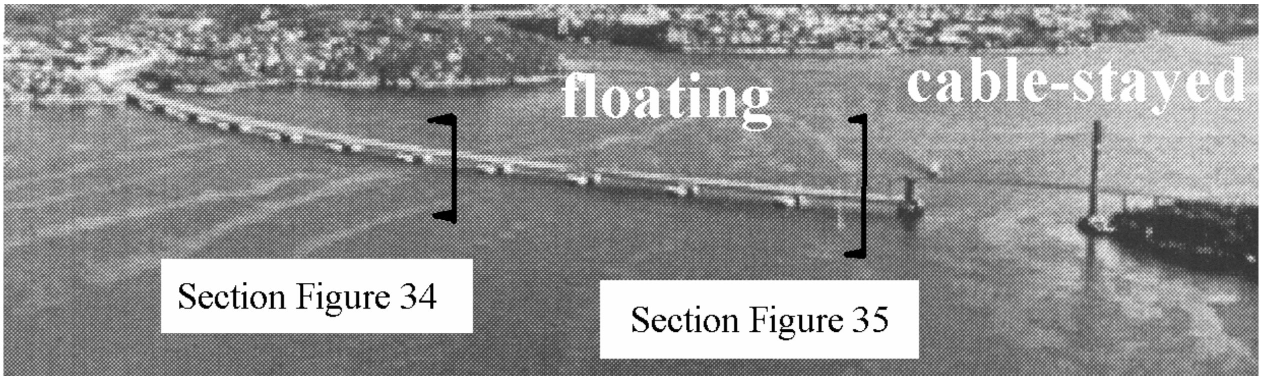
The first use of orthotropic bridge decks in Norway dates back to 1957 when the Krakeray Bascule Bridge was completed (reference #4). Norway has several complex aerodynamic wing type orthotropic suspension and cable-stayed bridges. Two unique orthotropic steel deck bridges are the Bergøysund floating bridge (reference #2 ) and the Nordhordland floating bridge across the fiords of Norway. The Bergøysund Floating Bridge is comprised of floating concrete pontoons with painted steel truss superstructure (Figures # 31 & # 32). Floating orthotropic bridges become very economical for Norwegian fjords, which are actually deeper than the adjacent Atlantic Ocean floor. Lateral stability of the entire bridge from ocean waves is provided by arch-shaped (in plan view) rather than cables with anchors in the 300-m deep fjord. The lateral stability of the top chords of the trusses is assisted by transverse stiffness of the orthotropic deck. The 3-dimensional space truss is built of hollow steel pipes tubular joints, which have the minimum exposed area to resist corrosion. Detailing and design of these joints were based on experiences developed for tubular offshore structures built in the North Sea. The closed trapezoidal rib was used, since the bridge is totally exposed to corrosive salt-water spray. Also it was very important to minimizing weight reduce the size of the concrete pontoons which were used to avoid future painting in the ocean water. This bridge is a state of the art solution utilizing offshore oil platform technology combined with floating bridge design technology


BERGøYSUND FLOATING BRIDGE, NORWAY Courtesy of IABSE [Figure # 31]

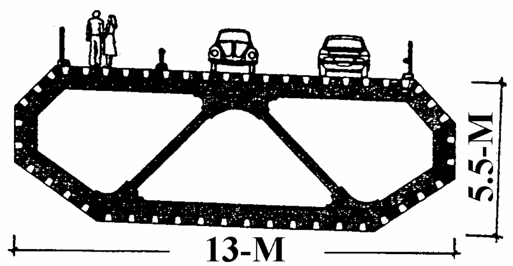
BERGøYSUND FLOATING BRIDGE, NORWAY – ELEVATION VIEW Courtesy of IABSE [Figure # 32]

## The Nordhordland Orthotropic Steel Deck Bridge of Norway

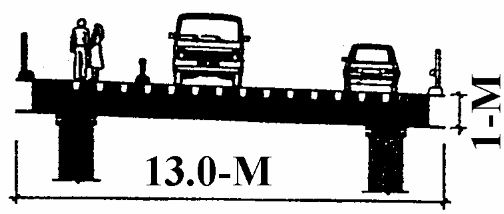
The Nordhordland Bridge across the Salhus fjord is Norway's second floating bridge and the world's largest floating bridge (Meas, Lande, and Vindoy, 1994). The bridge was opened for traffic in 1994. The total bridge length is 1615m and consists of a high level cable stayed bridge 369m long and a floating bridge 1246m long. The floating bridge consists of a steel box-girder, which is supported on 10 concrete pontoons and connected to abutments with transition elements in forged steel. The main elements are a high-level cable-stayed bridge providing a ship channel and a floating bridge between the underwater rock Klauvaskallen and the other side of the fjord. The cable-stayed bridge provides a clear ship channel. A 350m long ramp is required to transition from the higher bridge deck on the cable-stayed bridge to the bridge deck on the directly on top of the octagonal steel box-girder 11m above the waterline. The steel box-girder of the floating bridge forms a circular arch with a radius of 1,700m in the horizontal plane. The girder is supported on 10 pontoons. The pontoons are positioned with a center distance of 113.25m and acts as elastic supports for the girder. The girder is designed without internal hinges. The bridge follows the tidal variations by elastic deformations of the girder. The steel box-girder is the main load-carrying element of the bridge (Figure # 34). The octagon girder is 5.5m high and 15.9m wide. The free height below the girder down to the waterline is 5.5m allowing for passage of small boats. The plate thickness varies from 14mm to 20mm. The plate stiffeners are traditional trapezoidal shaped and they are spanning in the longitudinal direction of the girder. The stiffeners are supported by cross-frames with center distance of maximum 4.5m. At the supports on the pontoons bulkheads are used instead of cross-frames, because the loads in these section are significantly larger than in the cross-frames. The plate thickness in the bulkheads varies from 8mm to 50mm. The box girder is constructed in straight elements with lengths varying from 35m to 42m. The elements are welded together with a skew angle of 1.2° to 1.3° for accommodation to the arch curvature in the horizontal plane. The cross section dimensions of the octagonal box-girder are constant for the length of the bridge. The stress level varies significantly over the length of the bridge. In the areas with the highest stresses, steel with a yield stress of ReH= 540 MPa is used.




Nordhordland Floating Bridge across Salhas fjord of Norway Courtesy of IABSE [Figure # 33 ]




Nordhordland Floating Bridge Courtesy of IABSE [ Figure # 34 ]

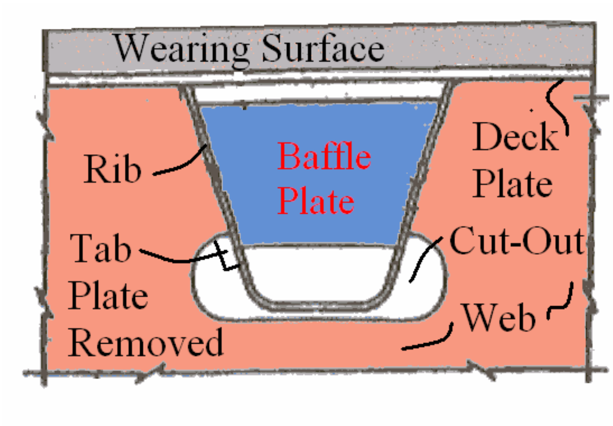



Nordhordland Floating Bridge Courtesy of IABSE [ Figure # 35 ]

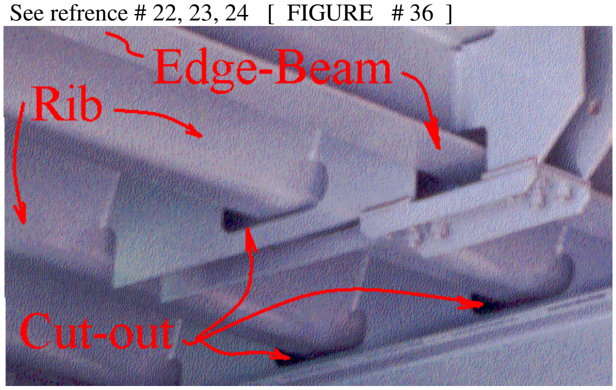
## Brief Summary Fatigue of Orthotropic Bridges

When orthotropic bridges were first introduced, the main emphasis was to minimize the weight. Unfortunately there were four collapses of steel box girder bridges killing the ironworkers, which is described in Reference # 2. The practicable balance between minimum weight and longer bridge life is a key design issue in orthotropic steel deck bridges. Researchers plus the owners of orthotropic steel deck bridges have been monitoring their performance. Research equipment for testing of the entire steel orthotropic deck system with wearing surface is available in all major universities (see Figure # 22). Comparing designs between countries is more complicated than just translating the languages (also more difficult because engineering slang or jargon varies with each country). Complicating the issue is that every country has a different vehicle live loading. An interesting graphic comparison between code minimum design vehicle loads of Germany, Belgium, Sweden, Norway, Finland, Netherlands, Italy, Spain, USA (HS 20), Switzerland, United Kingdom, France and Japan (see Reference#20 and Figure # 38). The author goes into more detail comparing the United Kingdom BS = British Standard code vs. USA (HS 20). These complexities make it more difficult to compare design and maintenance issues. However some Japanese codebooks are available in English versions. Several American orthotropic bridges have been fabricated in Japan, which allows them to study American designs in detail. Japanese research has also been extensive since they have the world’s longest span suspension bridge; cable-stayed bridge and floating bridge. All three bridges use orthotropic steel decks with wearing surfaces. Also in “Bridges and Roads” October 1998 and November 1999 of Orthotropic Steel Decks written by Prof. Shigeyuki Matsui of Osaka University; K. Ohta and Kazuhiro Nishikawa Head of the Bridge Division of PWRI, 1-Asahi, Tsukuba-shi, 305 Japan discuss research issues for their bridges. One topic is a summary of fatigue crack locations in their bridges. They do not give a summary of the actual amount of cracks occurring in the steel deck orthotropic bridges.

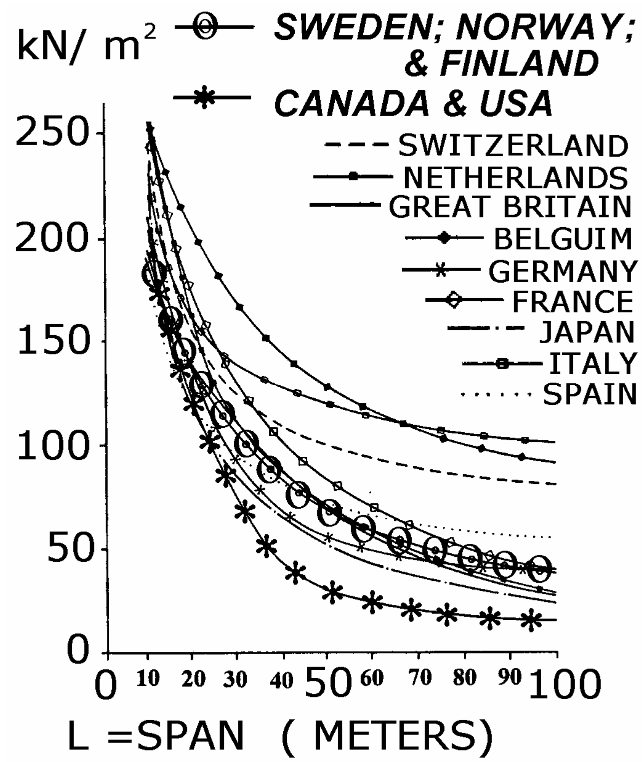
In the USA, Dr Fisher's studies on orthotropic steel decks have created a next generation system adopted by AASHTO code(see References # 2, #22, #23, #24 and # 42). An internal baffle plate positioned inside the trapezoidal rib makes the deck have a longer fatigue cycle life. This detail has been used on decks for suspension bridges in New York and California. Practicing design engineers have combined research findings and testing into new code design formulas and repair techniques. The durability of their designs is also very important to bridge design engineers (see Figures # 36 & # 37).




Dr John Fisher's Detail to achieve 100-year Fatigue Life
See refrence # 22, 23, 24 [ FIGURE # 36 ]




Dr John Fisher's Detail test section at Lehigh Photo by Mangus
[ FIGURE # 37 ]

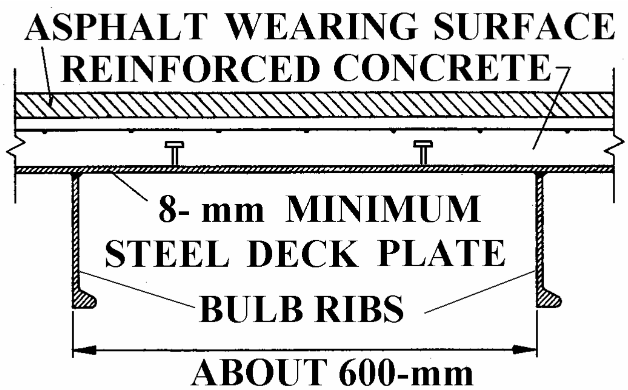



VARIOUS NATIONAL BRIDGE LOADINGS for 4-Lane Bridges (courtesy OECD ), Chatterjee, S. , "The Design of Modern Steel Bridges", BSP Professional Books, Oxford UK 1991 pp. 185 reference # 20 [ FIGURE # 38 ]

## Brief Summary of Wearing Surfaces for Orthotropic Bridges

Researchers in Europe and Asia have been testing new material systems. Also in "Bridges and Roads" Oct 1998 and Nov 1999 of Orthotropic Steel Decks written by Prof. Shigeyuki Matsui of Osaka University; K. Ohta and Kazuhiro Nishikawa Head of the Bridge Division of PWRI, 1-Asahi, Tsukuba-shi, 305 Japan discuss wearing surface issues for their bridges. One related topic discussed is a study of rapid cool down of steel deck bridges. A nice graph compares, the around the clock, rapid "cool-down" of a bridge deck above a river. The slippery surface on two California's smaller orthotropic bridges has required the posting of yellow warning signs.

Italian researchers are proposing a hybrid system that is shown in Figure #39. The trade-off of an increased dead weight is justified with the long-term knowledge of the actual useful life of composite reinforced concrete deck on steel superstructure. The orthotropic deck allows rapid erection of the superstructure and the need for an additional deck forming system. Thicker wearing surfaces dissipate wheel loadings to a larger number of ribs. Therefore, bridges with thicker wearing surfaces have a longer fatigue life, but they weight more. The Italian studies are available in Reference # 32.




RIO VERDE BRIDGE, ITALY - courtesy of IABSE Caramelli, S.; Croce, P.; Salvatore W. "The Composite Steel-Concrete Orthotropic Plate Bridge" Bridge Engineering Conference, March 2000 - Sharm El Sheikh, Sinai, Egypt Reference # 32 [ FIGURE # 39 ]

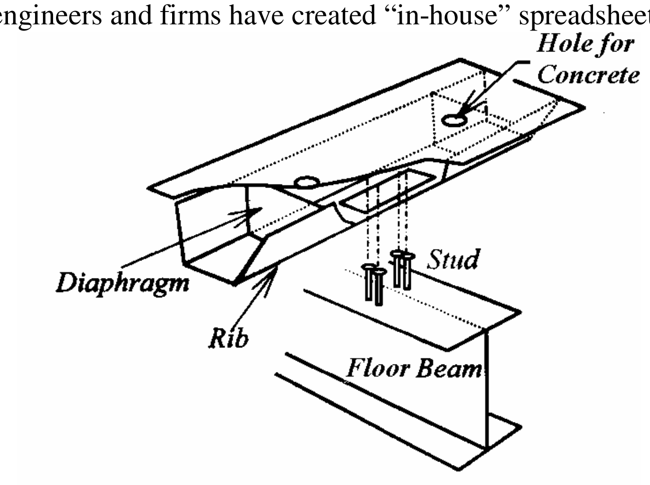
"Dense Mastic Surfacing of an Orthotropic, Bascule Bridge 73-125" Evers, R. C. courtesy of Ontario Ministry of Transportation and Communications (June 1977) Reference # 33 [ FIGURE # 40 ]

One wearing surface issue unique to bascule or drawbridges is the ability to take vertical shear loadings while the movable span is the raised position (see Reference # 33). Mechanical tabs to assist in this vertical loading to the wearing surface are shown in Figure # 40. This repair solution on the Canadian bridge has performed satisfactorily.

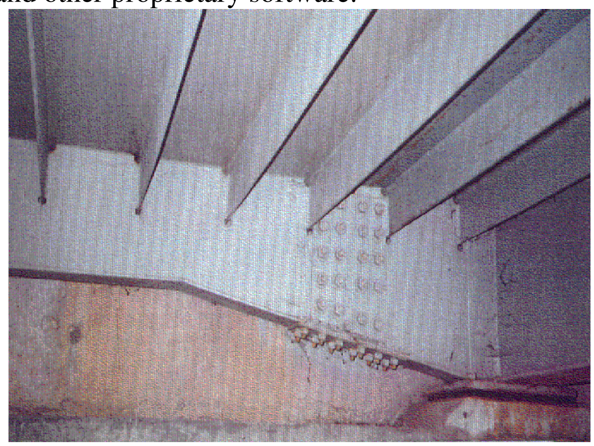
Steel companies and departments of transportation have built actual prototype bridges to monitor the wearing surface, fatigue life and all other bridge maintenance issues. A steel company prototype bridge is shown in Figure # 41. The Oregon Department of Transportation's prototype 1960's era bridge, which is still in service, is shown in Figure # 42. The Salem Bridge was 50% open ribs and 50% closed ribs to compare the long term durability. Caltrans (California Department of Transportation) research testing and wearing surfacing studies started in the 1960's (see Reference # 2). A very large bridge, San Mateo-Hayward, justified the widening of Ulatis Creek Bridge on I-80 in the city of Vacaville, California. The twin existing two-lane concrete bridges were widened to have three lanes of traffic in 1966. The low-speed lane three or truck lane (heavy truck traffic) on the eastbound bridge was widened with the open-rid orthotropic deck system of the proposed San Mateo-Hayward Bridge. Four wearing surface materials were applied in four adjacent deck areas. The winner of the contest was epoxy asphalt. The economics of the test was justified because the original wearing surface remains on the October 1967 San Mateo-Hayward Bridge. Also the Ulatis Creek Bridge's orthotropic lane on I-80 remains in service with epoxy asphalt. The wearing surface interacts with the steel deck and may be thinner over bolted splice plates. Suppliers, researchers and design engineers are monitoring all the various products and performance. Some wearing surfaces have failed too quickly. Caltrans has had to resurface one orthotropic bridge with trapezoidal ribs after 22 years of service (see References # 29 & # 44 ). Dutch systems for movable bridges were discussed in Reference #1. A Swiss firm, Aeschlimann, uses a different set of materials for the wearing surfaces on orthotropic bridges.

## Brief Summary of Design of Orthotropic Bridges

Birds and other creatures have nested in the hand holes for bolt splice for trapezoidal ribs used bridges built in the 1960's. Expanding inert foam has been placed inside the cells or trapezoidal ribs in California. This material is believed to prevent internal corrosion; nesting of creatures; and possibly help in delaying "cool-down" of slippery decks. Many engineers believe this is this best available solution at the moment. The coordination of orthotropic deck design research has not occurred in the USA, since the 1960's. Every designer is left to state-of-the-art literature search. Some major projects have had funds to perform project specific research. A world conference was held when four box girder bridges collapsed within a two-year period killing iron-workers (see Reference # 2). Traditional hand calculator methods are used to look at the design. Most practicing design engineers today have very powerful personal computers. A variety of "finite element" programs are available. In addition, non-linear finite element analysis is also performed. Many engineers and firms have created "in-house" spreadsheets and other proprietary software.




NIPPON STEEL SYSTEM, JAPAN Courtesy of IABSE[ Figure # 4 1 ]



PROTOTYPE BRIDGE --THE BATTLE CREEK BRIDGE ON COMMERCIAL STREET IN SALEM, OR The City of Salem owns and maintains the structure now, but it was designed by ODOT. This is a three span bridge with a main span of only 30ft. It is 77ft. long and 46.4 ft. wide. Half of the deck is an open rib design and the other half is a closed rib design. Photo courtesy of Casey Faucett City of Salem. [ Figure # 4 2 ]

Everything finally constructed is really a test structure. Engineers biannually monitor the real world performance of bridges. The FHWA is proposing the design of a bridge now be 100 years. Earlier orthotropic bridges have not been durable because the primary goal was to reduce steel weight. A moderate sized orthotropic bridge in the USA had a lot of fatigue cracks. The DOT owner decided to pour a concrete deck replacing the asphalt-wearing surface. This converted into a hybrid bridge using composite structure similar to a box girder with concrete deck. Since this fatigue retrofit was done a few years ago, the long-term results are not known. The DOT did not want to have endless studies on the fatigue cracks. Many small or moderate sized orthotropic bridges are not documented in the literature. If the project was documented it can be very hard to find, since most computer data base search engines limited to about the last 20 years. The majority of orthotropic bridges built in the 1960's are still in service and performing in an acceptable manner. Fishers' orthotropic steel deck fatigue studies now part of the AASHTO code (see Reference # 2)

## Brief Summary of the future of Orthotropic Bridges

Some experts are concerned about welding details, the excessive use of closed trapezoidal ribs and other issues (see References # 41 to # 44). The ASCE American Society of Civil Engineers created [www.orthotropic-bridge.org](http://www.orthotropic-bridge.org) and their first conference was held in August 2004, and proceedings are available. The 2$^{nd}$ conference is planned for August 2008. Matt J. Socha, PE is chair mjscohape@yahoo.com

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