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AT

HYATT REGENCY NORTH DALLAS

MOVABLE BRIDGES

11/09/2018

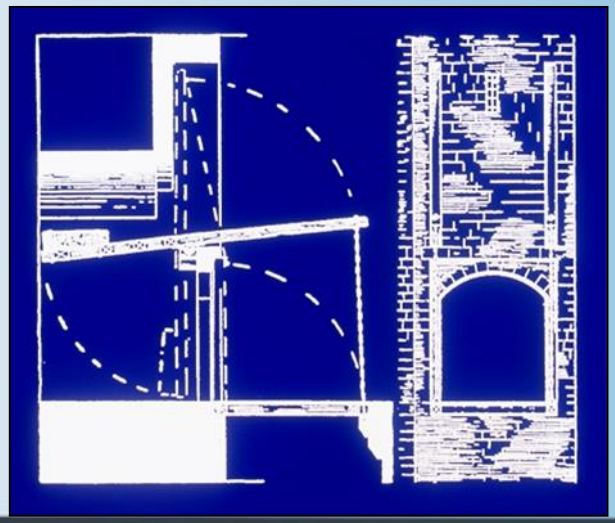
Presented by:
Jamal Grainawi, SE, PE

Historical Context

- *Movable Bridges: Bridges that can be opened to allow passage of a waterborne vessel. Either a drawbridge, a vertical-lift bridge, a floating bridge, or a swing (pivot) bridge. The drawbridge, or bascule, is the best known.*
- *It originated in medieval Europe, probably Normandy, as a defensive feature of castles and towns. It was operated by a counterweight and winch. The drawbridge that formed one span of Old London Bridge*

Types of Movable Bridges

- Drawbridge
- Bascule
- Swing
- Vertical Lift
- Floating Bridges – Pontoon
- Submersible bridge
- Retracting Bridges
- Folding Bridges
- Curling Bridge
- Fan Bridge
- Tilt Bridge



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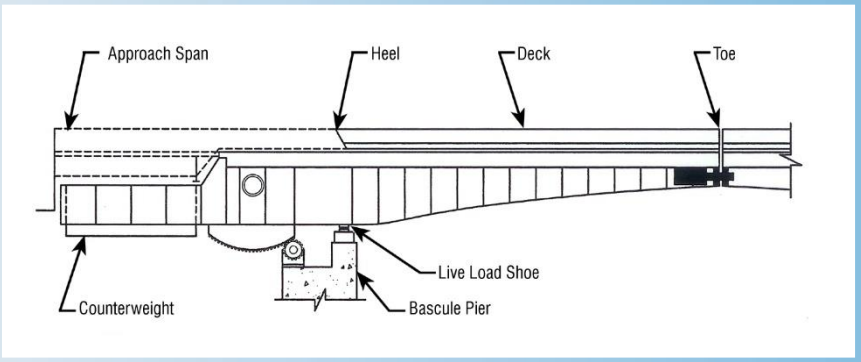

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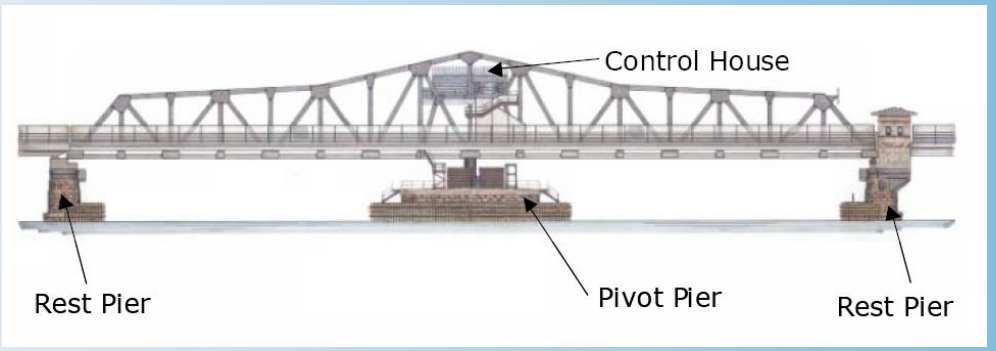

Swing Bridges

Types:

- Center Bearing
- Rim Bearing
- Combined Bearing
- Equal Length Arms
- Bobtailed Spans
- Single or Double-Swing-Span bridges

Swing Bridges

Advantages:

- Unlimited Vertical Clearance
- Low Profile
- Relatively Small Piers
- Fixed bridge when closed
- Dead Load is Balanced about Center Support for Equal Length Arms – CWT is not required

Swing Bridges

Disadvantages:

- Hazards to Navigation
- Need to Protect Superstructure
- Pivot Pier in the Center of the Channel
- Greater ROW Required
- Difficult Phased Construction
- Disruptions to Traffic (Future Rehabilitation)

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Vertical Lift Bridges

Advantages:

- First Cost
- Simplicity
- More Efficient at Longer Spans

Vertical Lift Bridges

Advantages:

- Wider Channel
- Limited Land Acquisition
- Extra Bridges
- Much More Rigid
- Faster Operation than Swing Bridges

Vertical Lift Bridges

Disadvantages:

- Restricted Vertical Clearance
- Highest Cost (Maintenance)
- High Profile (Tall Towers)

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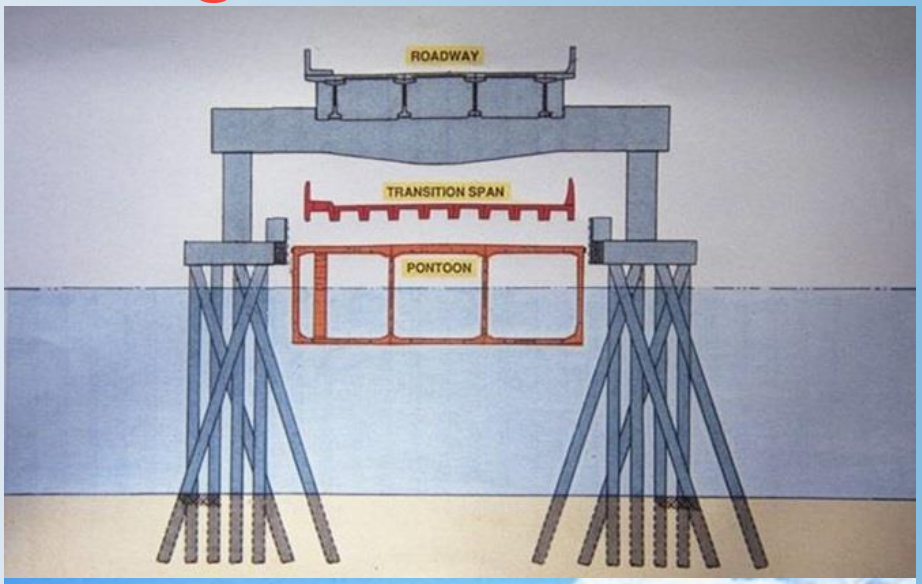

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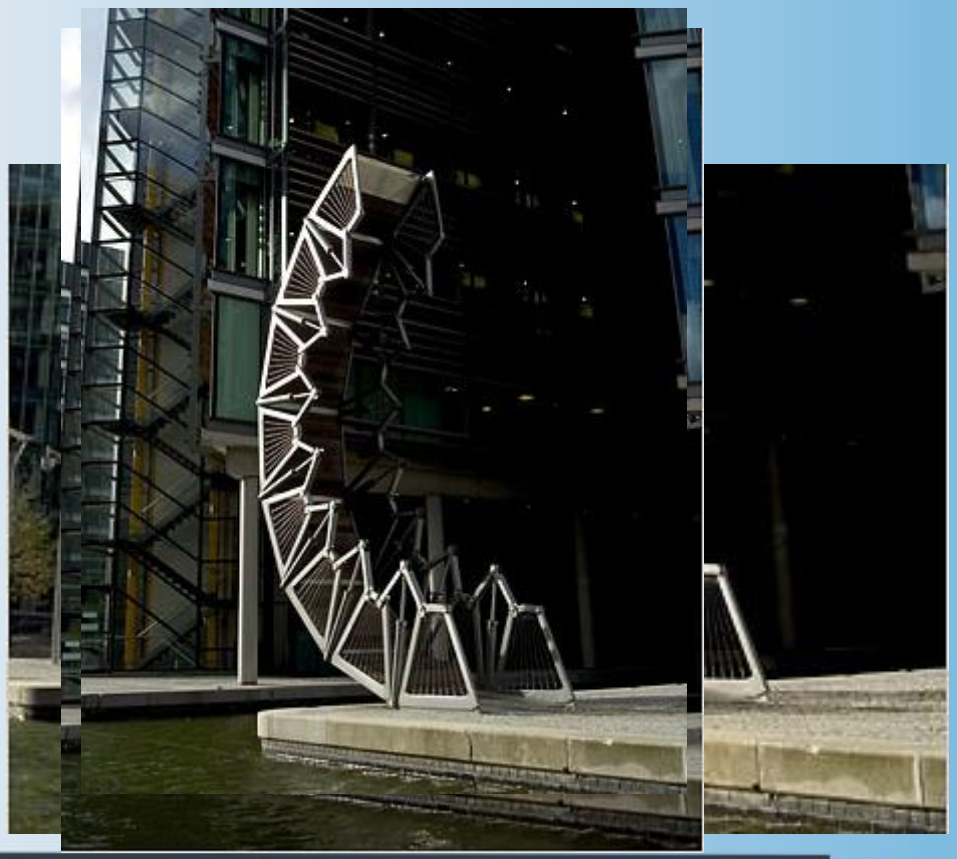

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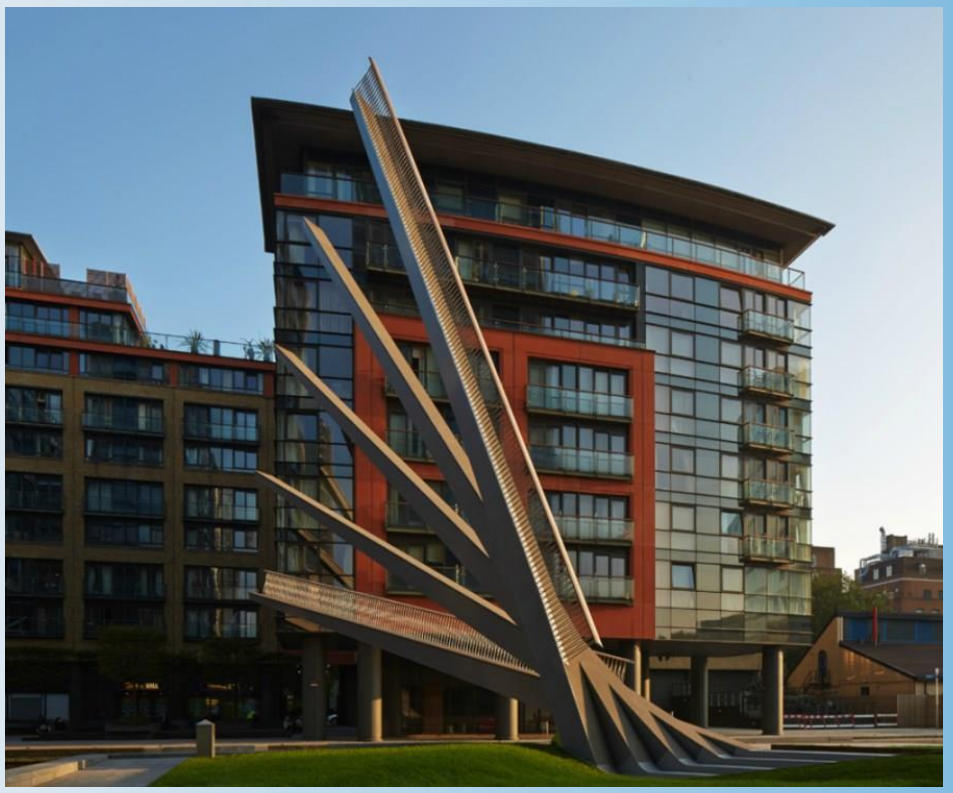

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Other Types of Movable Bridges

- Transporter Bridge

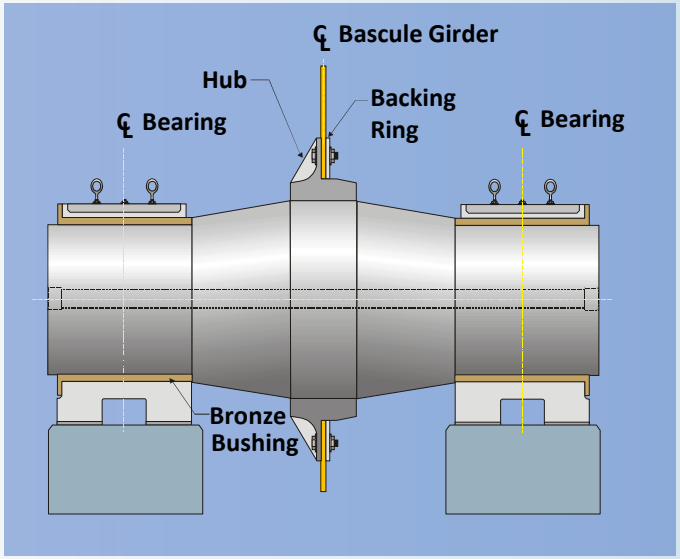
Other Types of Movable Bridges

- Transporter Bridge

Types of Bascule Bridges

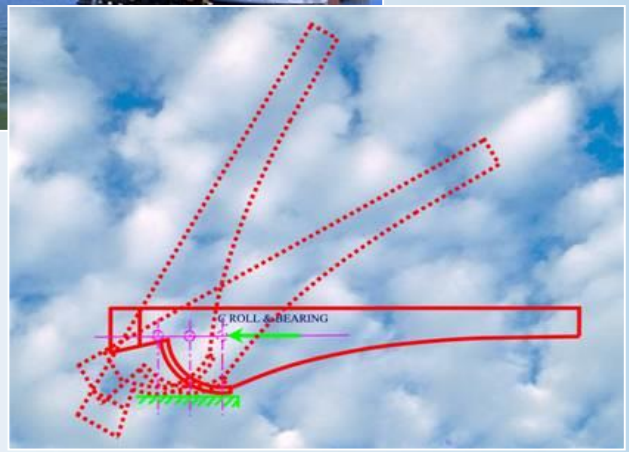
Bascule Bridges

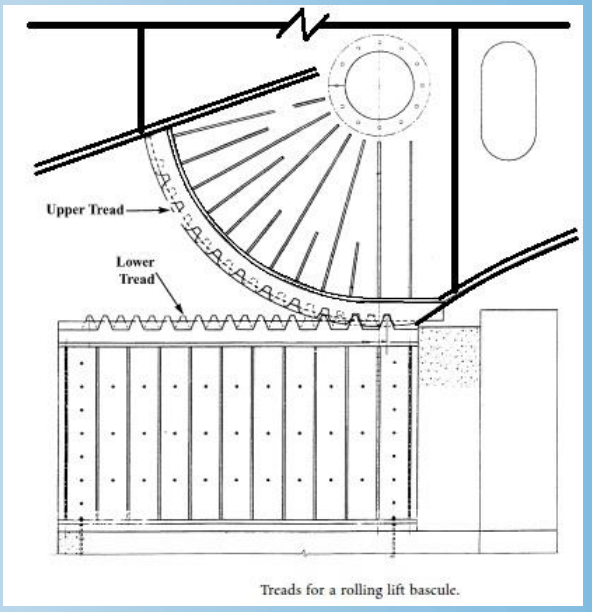
Trunnion Type



Bascule Bridges

Rolling-lift “Scherzer”





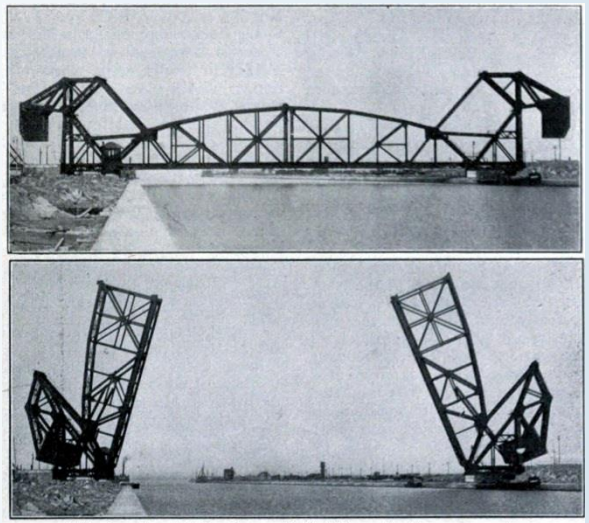
Treads for a rolling lift bascule.

Bascule Bridges

- Single-leaf
- Double-leaf
- Double-Deck

Bascule Bridges

- Counterweight below Deck / Roadway
- Overhead Counterweight



Historical Photos of Bridge in Lowered and Raised Position. Source: The Contract Record, 1915. Digitized By Internet Archive

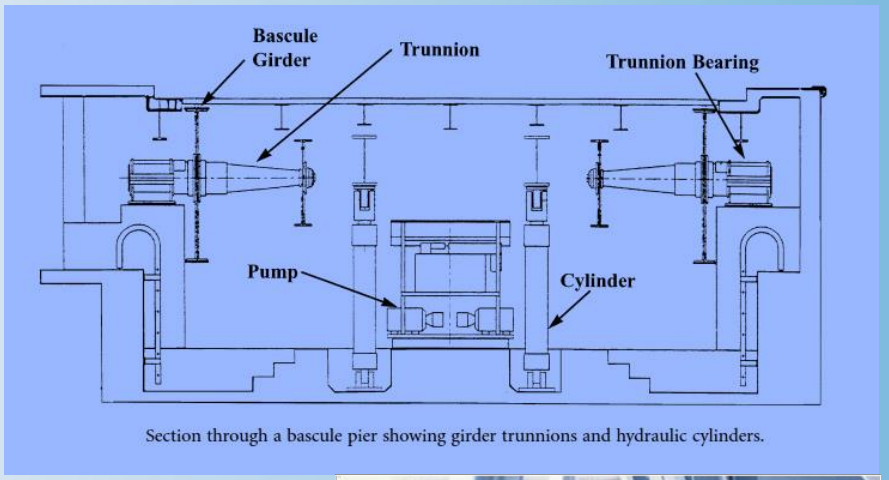
Bascule Bridges

- Open Pier
- Closed Pier

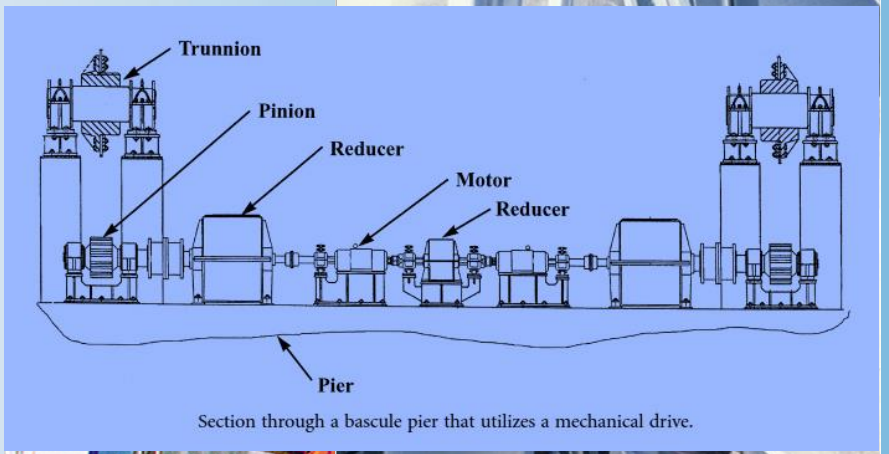
Bascule Bridges

Different Drive Systems:

- Hydraulic systems
- Mechanical drive: electric motors with gears



Section through a bascule pier showing girder trunnions and hydraulic cylinders.



Section through a bascule pier that utilizes a mechanical drive.

Bascule Bridges

Advantages:

- Provides Unlimited Vertical Clearance
- Economical for Most Waterways
- Fastest Operation
- The leaf when open acts as a barrier & protect traffic

Disadvantages:

- Operational problems can occur due to span imbalance
- Keeping counterweight pit dry
- Center locks, tail locks
- Staged construction
- Span limitation - 200 ft. for single-leaf & 350 ft. for double-leaf bridges.

Additional Reference Source

https://www.linkedin.com/groups/2120061

Thank you

Questions?

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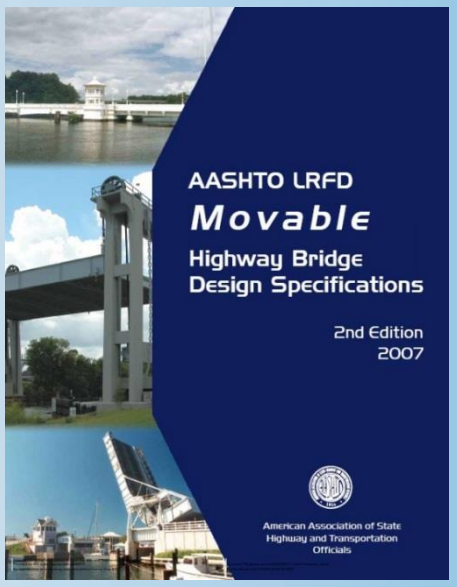
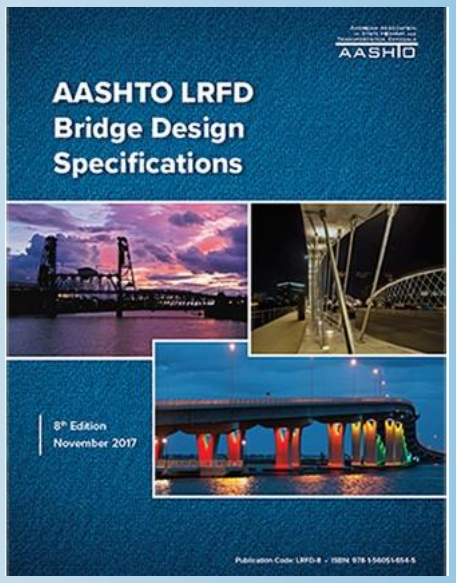
Bascule Bridge Design

Bascule Bridge Design

Codes:

- AASHTO LRFD Movable Highway Bridge Design Specification, 2nd Edition - 2007 with Interims through 2015
- AASHTO LRFD Bridge Design Specifications - Customary U.S. Units- 8th Edition - 2017
- Local DOT Applicable Manuals

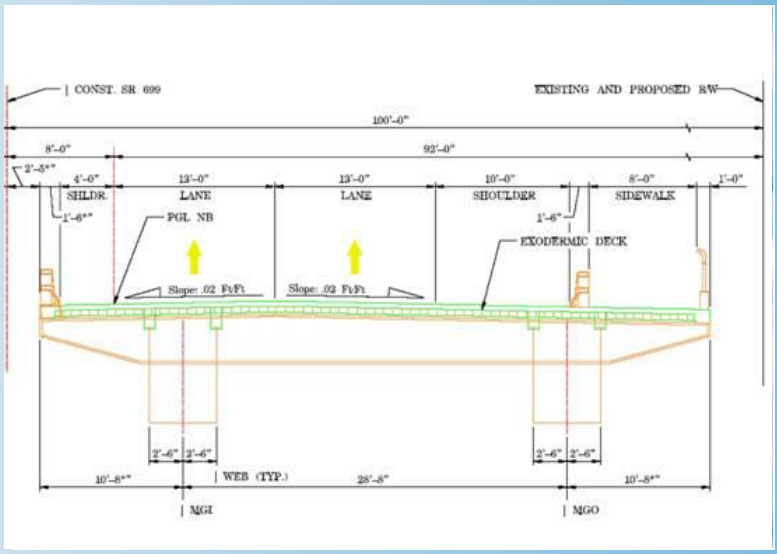




Bascule Bridge Design

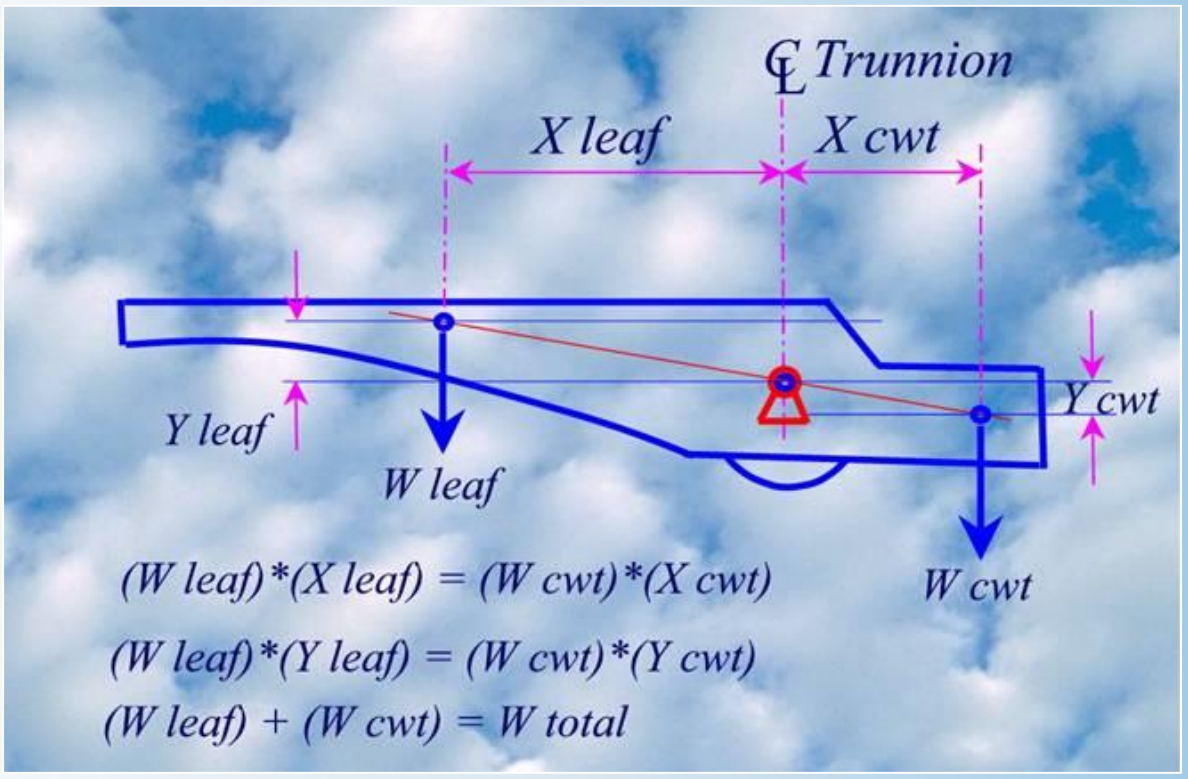
Unique Features:

- Support Configuration
- Framing Configuration
- Span Balance
- Operational Clearances
- Loading
- Trunnion
- A rear live load anchorage
- A forward live load bearing
- Center lock



Bascule Bridge Design

Span Balance:



Bascule Bridge Design

Span Balance:

- Reduce Operational Loads
- Positive Reaction on Live Load Shoe approx. 1.5 kips per Girder (Tip-heavy)
- Assist in Lowering the Leaf
- Allow for Vertical and Horizontal Adjustment

Bascule Bridge Design

Span Balance:

- Counterweights:
- Reinforced Concrete; Heavyweight Concrete; Balance Blocks or Steel Ballast / Steel Transition Slabs (10-14T)

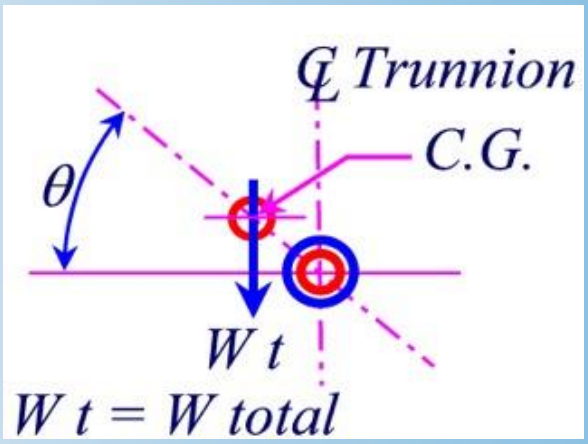
- Typical Counterweights weigh 3-4x more than the weight of the movable span
- Adjustment Pockets
- Design new bascule bridges such that the center of gravity may be adjusted vertically and horizontally

Bascule Bridge Design

Span Balance:

- Mechanical Drive
- C.G. of the Leaf is located Forward of the Trunnion and Located at an Angle < 20 Degrees above or below a Horizontal Line through Trunnion.

- Leaf Heavy in the Closed Position and Tail Heavy in the Fully Open Position.

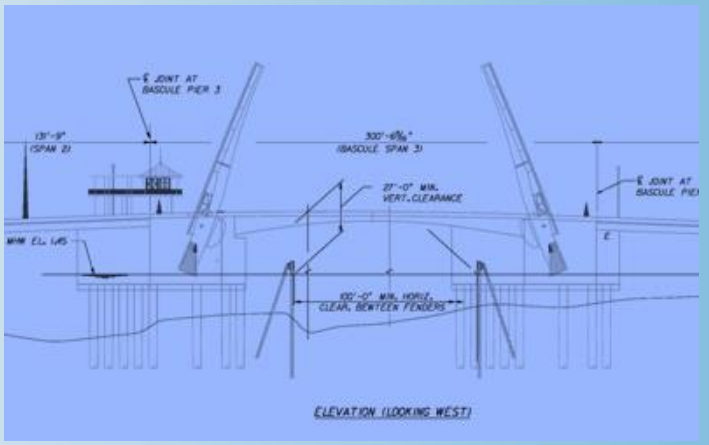


Bascule Bridge Design

Operational Clearances:

- Face to Face Fender System
- US Coast Guard Requirements
- Vertical Clearance
- Horizontal Clearance

- Due to the path they travel, bascule bridges typically present the most challenging clearance issues to designers.



Bascule Bridge Design

Loading-Dead Loads:

- All Dead Load is Carried by Trunnion or Track Girders
- Deck Dead Load W/ Leaf in Open Position
- Operational Dead Load Impact
- Leaf Cantilevered from Trunnion w/ Leaf in Any Position
- Span Balance – Leaf Heavy

Bascule Bridge Design

Loading-Wind Loads:

- Wind Loads w/ Leaf Raised (Open)
- Leaf Normally Closed
- Leaf Normally Open
- Wind Loads w/Leaf Closed –As Fixed Bridge - per AASHTO Std. Specs. or LRFD Specs.
- Leaf Cantilevered from Trunnion w/ Leaf in Any Position (on projected Area)

Bascule Bridge Design

Loading-Live Loads:

- Live Load and Impact (per AASHTO)
- Twice Normal Impact for End Floor Beams
- Simple Distribution of Loads from Deck to Stringers to Floor Beams to Main Girders
- Center Lock Transfer Live Loads

Bascule Bridge Design

Element Design:

- Deck, Sidewalk & Traffic Barrier
- Superstructure – Stringers, floor beams/ SW Brackets CWT. girders, main girders/ trusses and towers
- Substructure & Foundation
- Bridge House
- Span Balance (Counterweight Elements), Center & Tail locks
- Pier protection cell and fender system

Bascule Bridge Design

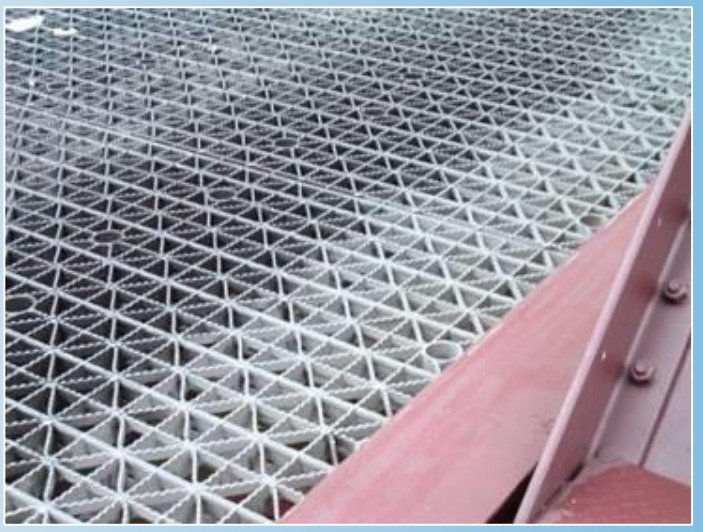
Deck and Sidewalk Design:

- Allow safe passage of vehicular and pedestrian traffic
- Withstand repeated 75 degree rotation
- Add minimal weight to the movable span (1 lb. of deck weight requires approx. 3 lbs. of counterweight)
- Add minimal wind load on raised leaf
- Require no complex details for securing to floor framing section

Bascule Bridge Design

Deck Types:

- Open Steel Deck
- Half-Filled Deck
- Solid Bridge Deck
  - Exodermic / Concrete
  - FRP (Fiberglass Reinforced Polymer)
  - Orthotropic
  - Aluminum
  - Sandwich Plate System
  - Timber



Bascule Bridge Design

Open Steel Deck

Advantages:

- Most common type for movable bridge decking
- Light weight, low wind resistance, and moderate cost
- Simple details
- Can be attached to framing while the bridge in open or closed position
- No drainage needed on the bridge

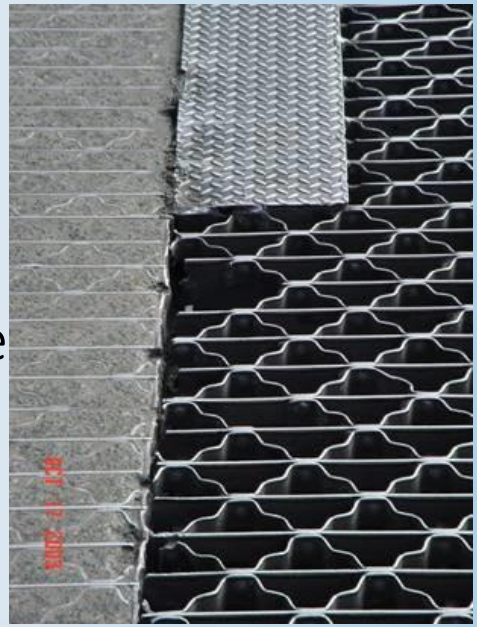
Bascule Bridge Design

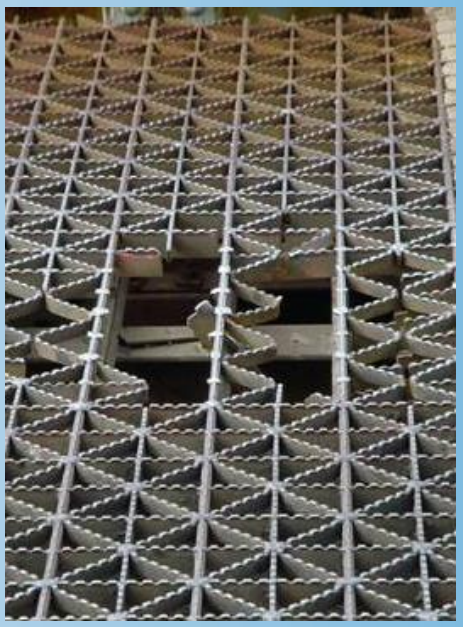
Open Steel Deck

Disadvantages:

- Poor ride quality and poor skid resistance
- High noise levels
- Openings allow chloride and debris to accumulate on the floor system
- Fatigue Prone

- Internally Welded grating
- Connections to Stringers





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Deck Types:

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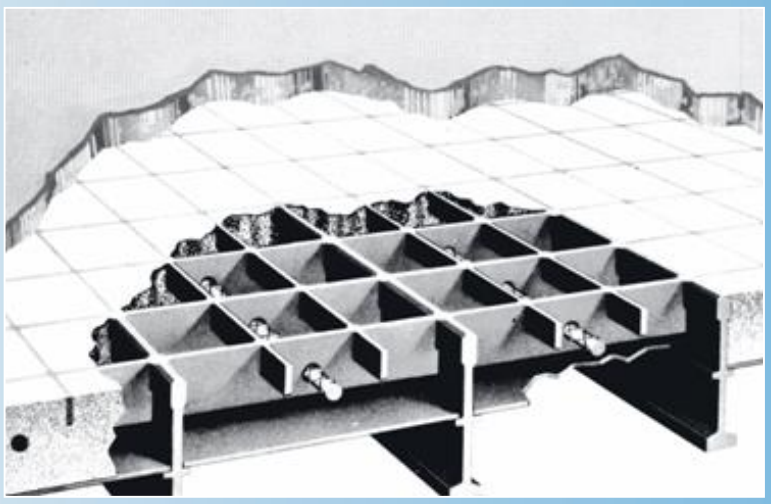

Bascule Bridge Design

Half-Filled Steel Deck

Advantages:

- Provides a solid driving surface, better skid resistance and better riding surface
- Protects floor system from chloride and debris run-off
- Less noise than open grid deck
- Bicyclists friendly surface
- Can be pre-cast (half filled in shop)
- Can be attached to framing while the bridge in open or closed position

Bascule Bridge Design

Half-Filled Steel Deck

Disadvantages:

- More costly than open steel deck
- More wind resistant and three times heavier than open steel deck
- Requires deck drain system
- Poor performance of concrete fill due to poor consolidation in small, shallow spaces in gird
- Complex deck joints to seal out the water

Bascule Bridge Design

Deck Types:

- Open Steel Deck
- Half-Filled Deck
- **Solid Bridge Deck**
  - **Exodermic / Concrete**
  - FRP (Fiberglass Reinforced Polymer)
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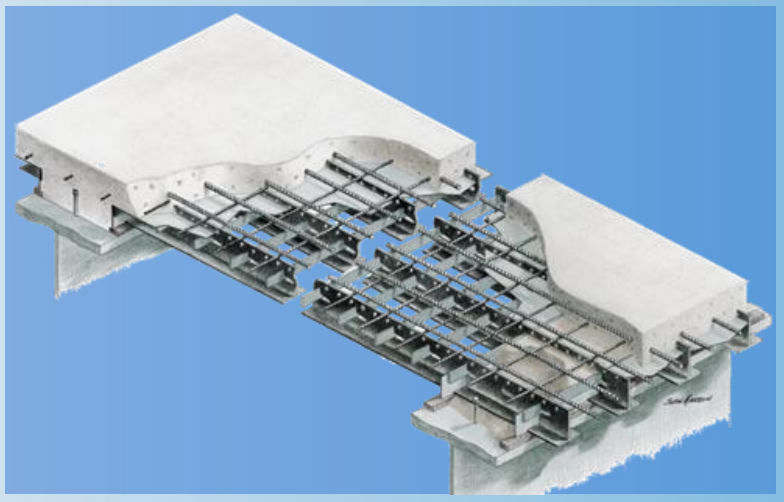

Bascule Bridge Design

Exodermic Deck

Advantages:

- Provides a solid riding surface and good skid resistance
- Protects floor system from chloride and debris run-off
- Low noise level
- Bicyclists friendly surface
- Composite action - allows long spans to be used
- Cross slope can be used on the bridge to allow for a better drainage
- Can be attached to framing while the bridge in open or closed position

Bascule Bridge Design

Exodermic Deck

Disadvantages:

- More costly than open or half-filled grid deck
- 17% heavier than half-filled grid deck
- Larger framing, counterweight, and machinery
- Concrete can only be cast in place while the bridge in the closed position

Bascule Bridge Design

Deck Types:

- Open Steel Deck
- Half-Filled Deck
- **Solid Bridge Deck**
  - Exodermic / Concrete
  - **FRP (Fiberglass Reinforced Polymer)**
  - Orthotropic
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Bascule Bridge Design

FRP Deck

Advantages:

- Provides a solid riding surface and good skid resistance
- Protects floor system from chloride and debris run-off
- Low noise level
- Light weight - less than open steel deck and 20% of concrete deck
- Rapid, cost-effective construction: only light equipment used

Bascule Bridge Design

FRP Deck

Advantages (cont.):

- Corrosion-resistant: better suited to de-icing chemicals
- Factory fabrication
- High-quality manufacturing process
- Can be molded to any shape
- Ease of transport and handling
- The FRP panels can be attached to the framing while the bridge in the open or closed position

Bascule Bridge Design

FRP Deck

Disadvantages:

- Cost is higher than other solid deck
- Some issues with the connections of the FRP panels to the steel structure
- Lack of Structural Engineers & Contractors experienced using FRP
- New Material – damage due to sudden impact?

Bascule Bridge Design

Deck Types:

- Open Steel Deck
- Half-Filled Deck
- **Solid Bridge Deck**
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  - FRP (Fiberglass Reinforced Polymer)
  - **Orthotropic**
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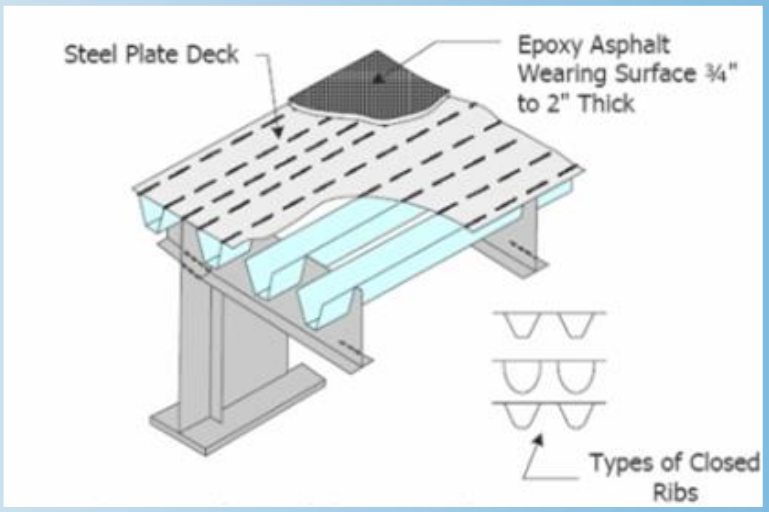
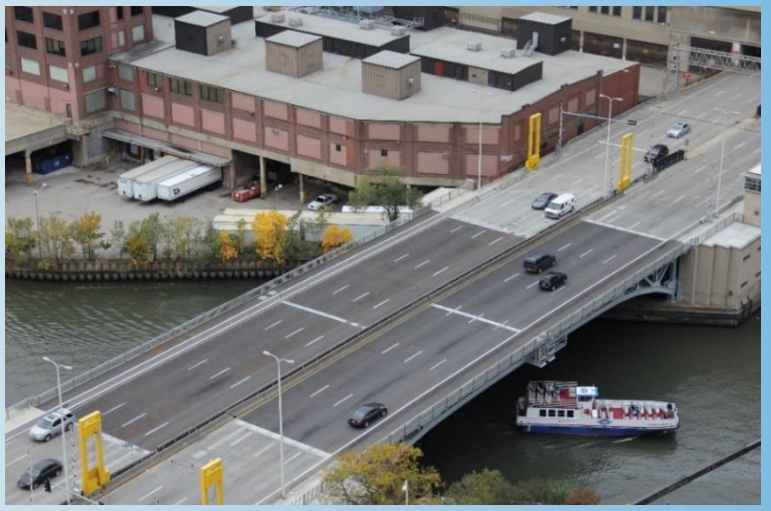




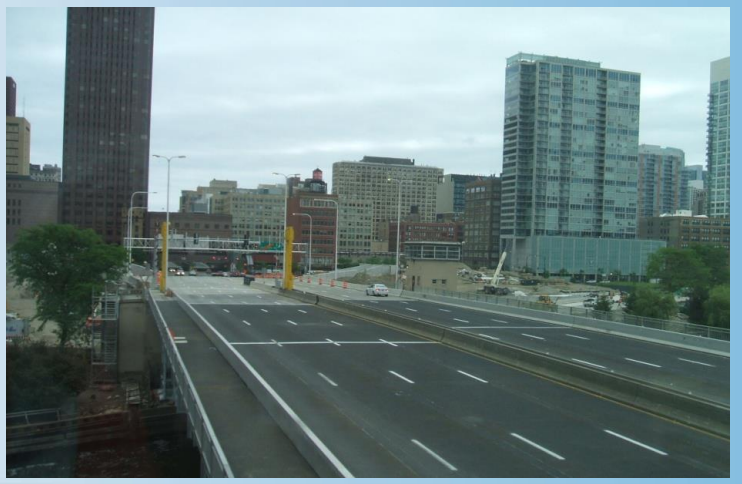
Bascule Bridge Design

Orthotropic Deck:

- Flat, thin steel plate stiffened by a series of closely spaced longitudinal ribs at right angles to the floor beams

Advantages:

- The deck acts integrally with the steel superstructure



Bascule Bridge Design

Orthotropic Deck

Advantages:

- An orthotropic deck becomes the top flange of the entire floor system
- Lowest self-weight of solid decks results in cost saving for foundations, motors, CWT., etc.
- Prefabricated and lightweight component; can be built quickly
- Another potential advantage is lower life-cycle costs.
- Provides a solid riding surface and good skid resistance
- Protects floor system from chloride and debris run-off
- Low noise level
- Can be attached to framing while the bridge in open or closed position

Bascule Bridge Design

Orthotropic Deck

Disadvantages:

- In the past: – Orthotropic deck were not covered by most bridge design codes. Now:- Manual for Design, Construction and Maintenance of Orthotropic Steel Deck Bridges, FHWA, 2012
- Refined Analysis is needed
- Wearing Surface Performance
- Fatigue Crack Issues
- Higher Initial Cost

Bascule Bridge Design

Deck Types:

- Open Steel Deck
- Half-Filled Deck
- **Solid Bridge Deck**
  - Exodermic / Concrete
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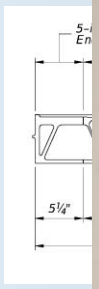

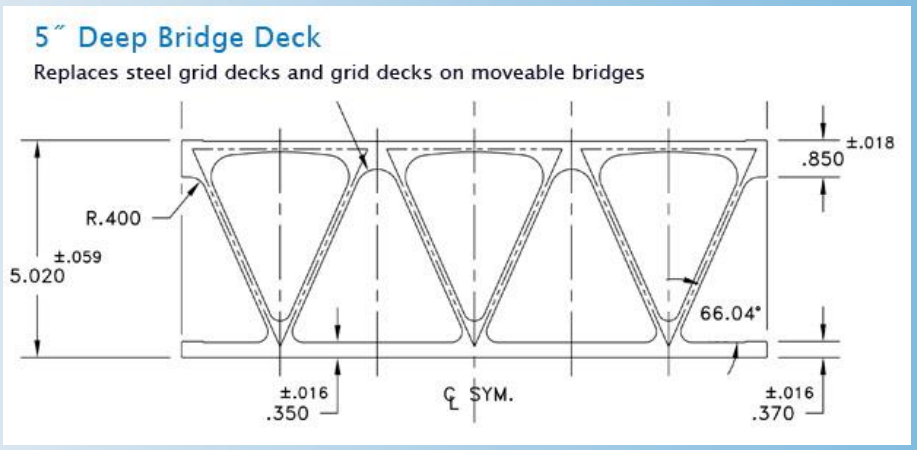

Bascule Bridge Design

Aluminum Deck

Advantages:

- 80% lighter than concrete
- Increased bridge width and capacity
- Corrosion-resistant: better suited to de-icing chemicals
- Requires no painting and minimal maintenance
- Low temp. toughness
- Ideal for bridges and other highway structures in cold weather climates
- Rapid, cost-effective construction: no formwork or extensive cure time, as with concrete
- Short downtime for deck replacement

Bascule Bridge Design

Aluminum Deck

Disadvantages:

- Connection to steel framing
- Different thermal expansion rates between aluminum and steel
- Requires Teflon pads between the aluminum and the steel stringers to isolate due to dissimilar metal corrosion
- The creep in the Teflon would not allow friction bolts to stay tight – thus the panels would rattle or slip when the leaf rotated

Bascule Bridge Design

Deck Types:

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- Half-Filled Deck
- **Solid Bridge Deck**
  - Exodermic / Concrete
  - FRP (Fiberglass Reinforced Polymer)
  - Orthotropic
  - Aluminum
  - **Sandwich Plate System**
  - Timber

Bascule Bridge Design

Sandwich Plate System

Advantages:

- 70% lighter than concrete
- Extending the life of deficient bridges by reducing the dead load
- These prefabricated components allow short downtime for deck replacement
- Works compositely with the bridge superstructure
- Rapid, cost-effective construction: no formwork or extensive cure time, as with concrete
- Impact Resistance

Bascule Bridge Design

Sandwich Plate System

Disadvantages:

- As with other bridge deck systems, the SPS system does come with some disadvantages:
- High Initial Cost
- There are no design standards for an SPS bridge deck system

Bascule Bridge Design

Deck Types:

- Open Steel Deck
- Half-Filled Deck
- Solid Bridge Deck
  - Exodermic / Concrete
  - FRP (Fiberglass Reinforced Polymer)
  - Orthotropic
  - Aluminum
  - Sandwich Plate System
  - Timber

Bascule Bridge Design

Deck Joints:

- Center / Rear Joints

Bascule Bridge Design

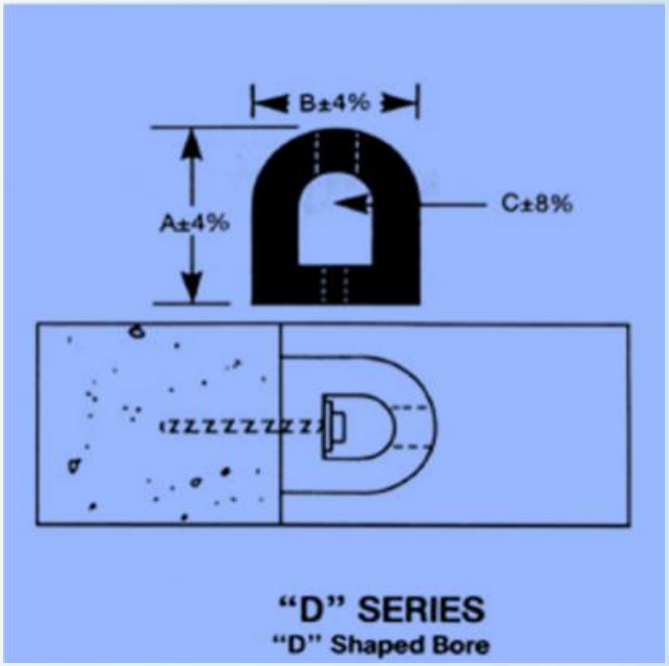
Pier Protection Cell & Fender Systems:

- The purpose of the Fender system is to absorb the energy of the ship impact
- The total energy depends on:
  - The size of vessel in displacement tons
  - Angle of approach
  - Impact velocity normal to fender
  - Hydraulic effect
  - Fender design & Type

Bascule Bridge Design

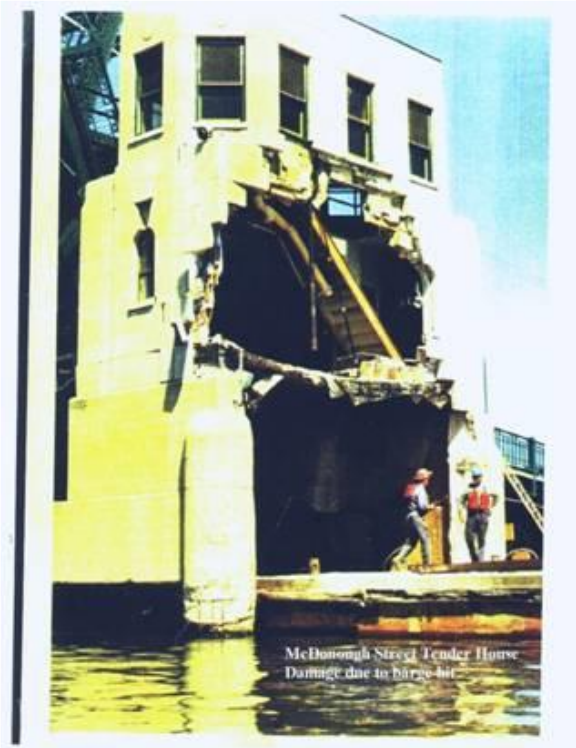
Pier Protection Cell & Fender Systems (cont.):

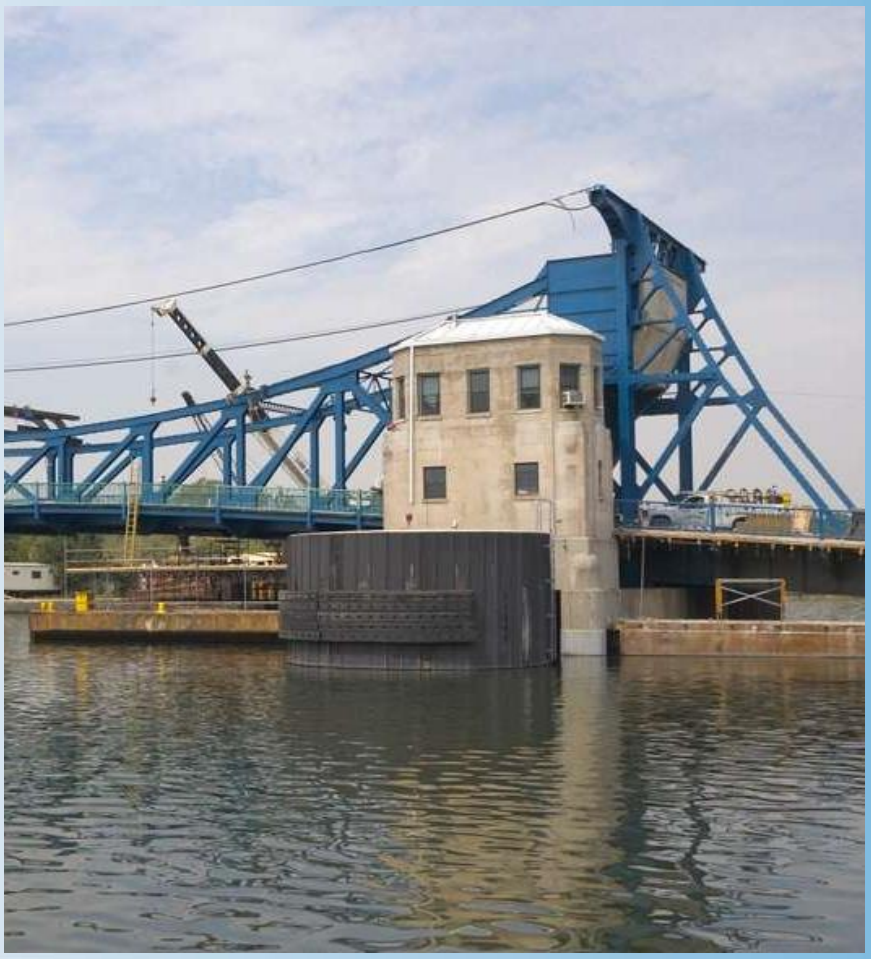
- D-Shaped Fenders



Bascule Bridge Design

Pier Protection Cell & Fender Systems (cont.):





Bascule Bridge Design

Bridge House Design:

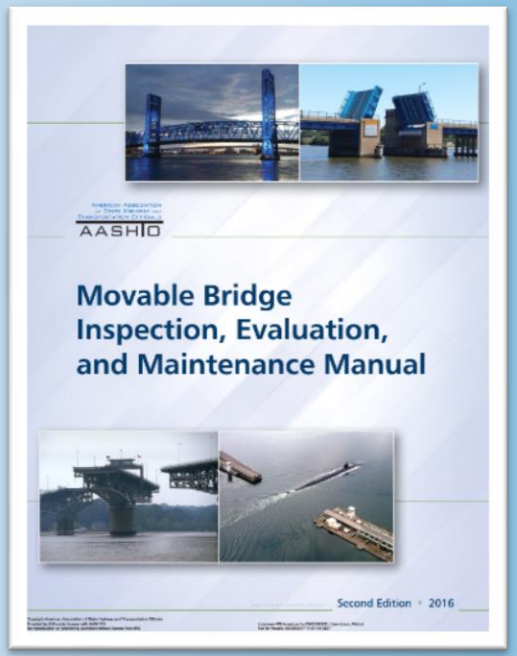
- Design of control houses should comply with the Building Code & OSHA requirements
- Consideration should be given to lines of sight form control station during column sizing and spacing

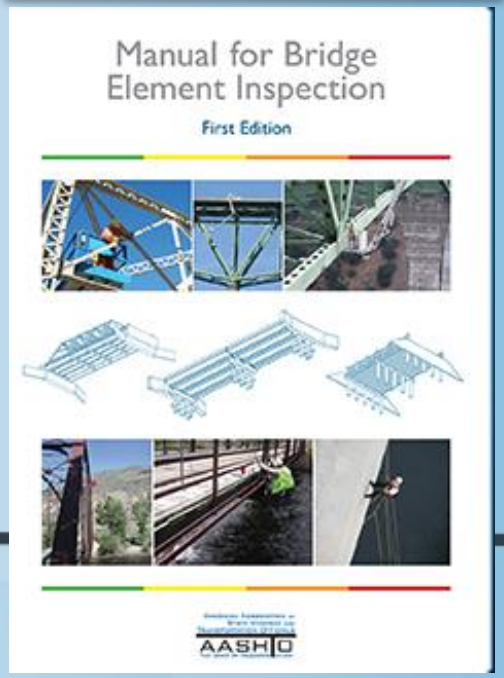
Inspection Challenges

Inspection Challenges

Codes/References:

- Movable Bridge Inspection, Evaluation, and Maintenance Manual, 2nd Ed. (MBI)
  - Updated 2016 by WSP under NCHRP Project 14-32
- AASHTO Manual for Bridge Element Inspection, 1st Edition, with 2015 Interim Revisions
- Local DOT Applicable Manuals





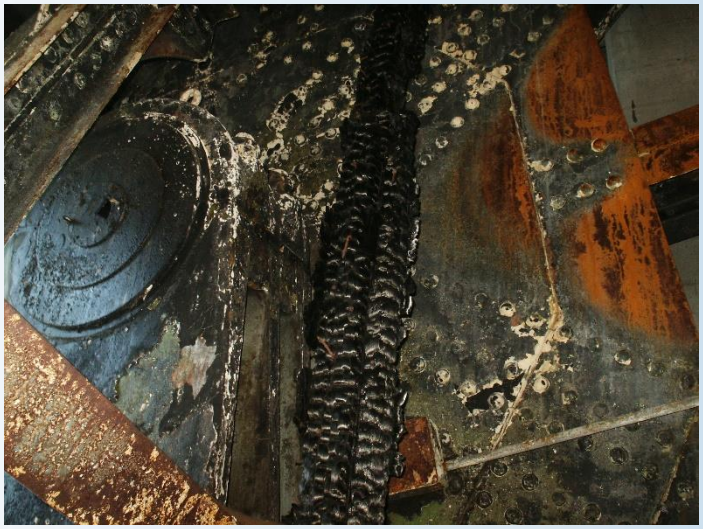
Inspection Challenges

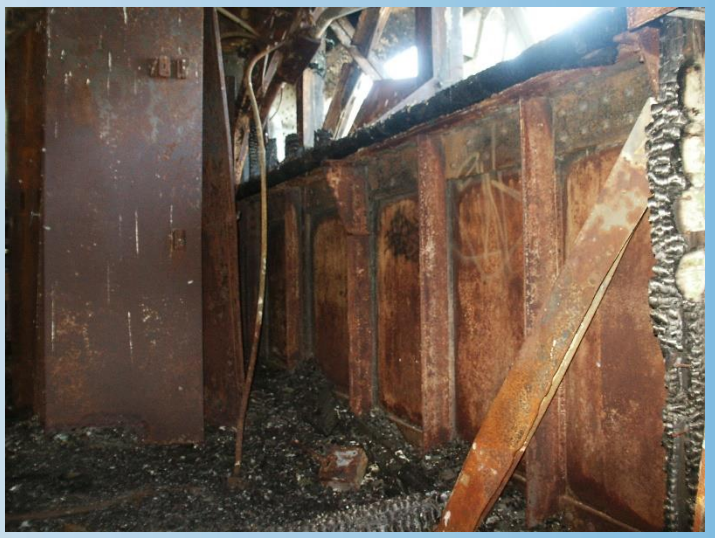
Method of Inspections:

- Bridge closure is required
- Using man-lift on a barge or snooper is expensive
- Limited access to elements
-

Inspection Challenge

- Access to bridge elements
- Vandalism



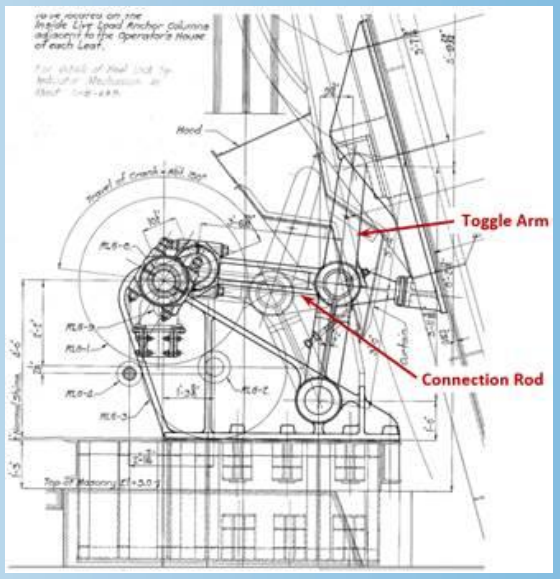


Design/Rehab Challenges

Design/Rehab Challenges

Existing Mechanical/ Structural Components:

- Some elements are encased in concrete, presenting rehabilitation challenges
- Replacing elements in stages also a challenge
- Access to elements
- Missing existing bridge plans/data



Design/Rehab Challenges

Safety/OSHA Requirements:

- Existing elements are difficult to update to current standards:
  - Ladders and handrails
  - Room clearances
  - Hatches
  - Stairways
- Existing bridge house lack space to update equipment

Design/Rehab Challenges

Remote Bridge Operation:

- With self-driving cars and now trucks, owners are interested in remote operation of movable bridges.
- A consideration for low-demand sites
- US Coast Guard has reservations about systems

A bascule bridge in a NYC borough has no visual on the bridge, but relies on CCR for remote operation

WisDOT, DelDOT, NJDOT are working on remote operating systems

Design/Rehab Challenges

Barrier Gate Crash Testing:

- Take precaution in plans and specs. when crash testing is required of gates
- Recommend separate pay item if testing in accordance with MASH is required due to high cost

Construction Challenges

Construction Challenges

Fit-up Issues:

- Shop Drawings are most accurate source of information but are not always available
- Section sizes may have changed since bridge was constructed

Field verification of dimensions likely required

Construction Challenges

Condition of fasteners:

- Are fasteners to mechanical equipment original or previously replaced?
- Can they be re-used?
- What if turned bolts cannot be removed by industry acceptable practices?

Construction Challenges

Unit Prices:

- Unit price of Structural Steel is higher than that of fixed bridge:
  - Complex repairs may require large quantity of rivets and temporary supports or shoring
- Unit prices of mechanical and electrical components

Specifications:

- Writing specification is more complicated:
  - Lack of standard specs.
  - Unique elements, limited manufacturers
  - Buy America waiver from FHWA?

Construction Challenges

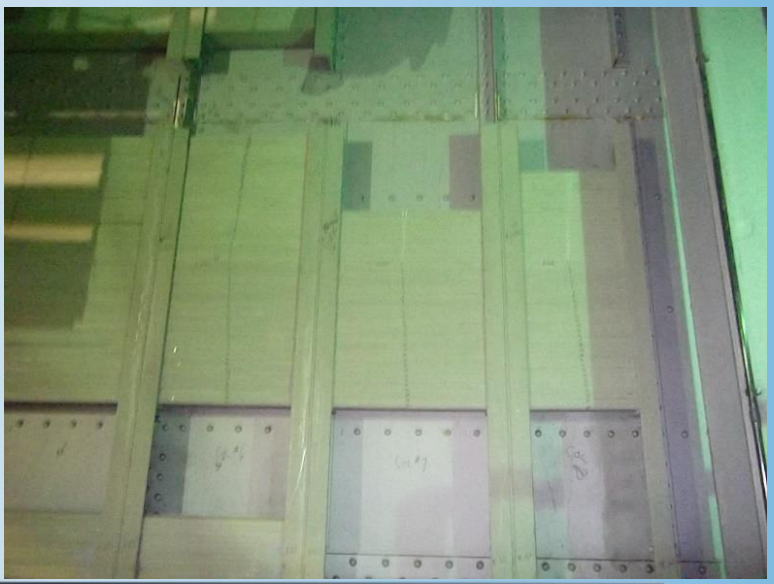
Contractor Lack of Familiarity with Movable Bridges

- Contractor removed steel stringers in a manner that subjected elements to additional loads
- Maintaining Bridge Balance using Roadway Barriers attached to truss members

Construction Challenges

Contractor Lack of Familiarity with Movable Bridges (cont.)

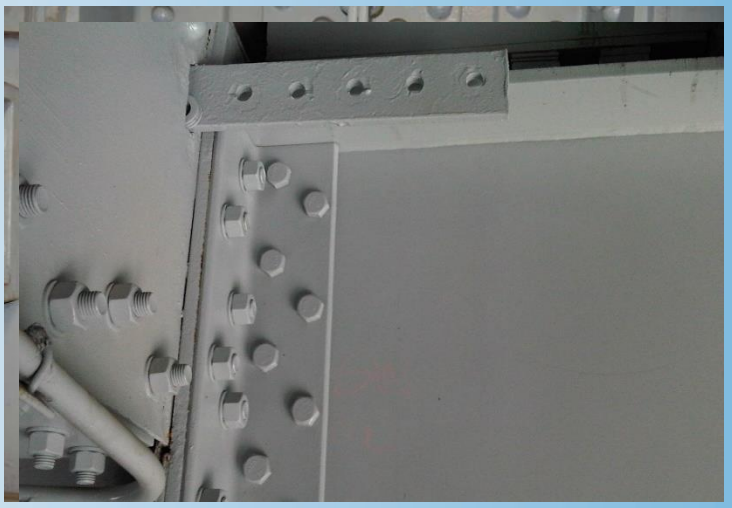
- Contractor installed excessive shims for deck. Result: the bridge required more counterweight than anticipated.
- Shims/additional counterweight were paid at high A.U.P.



Construction Challenges

Contractor Lack of Familiarity with Movable Bridges (cont.)

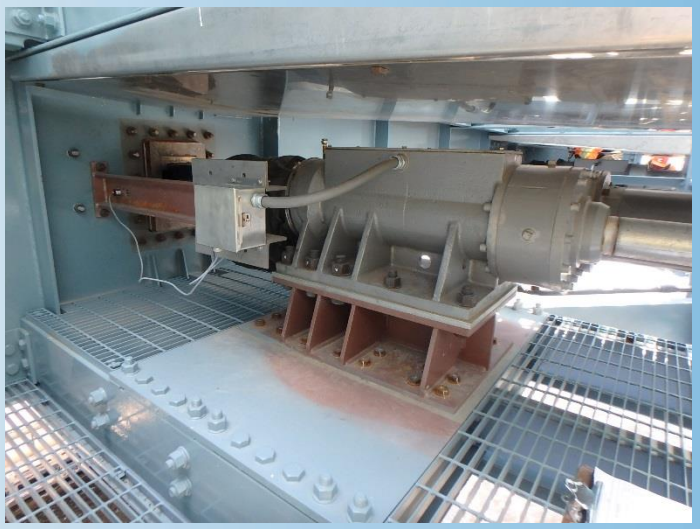
- Level of precision – Live Load Bearing Gap & Center lock
- Tie Plates to Sidewalk Bracket



Construction Challenges

"Approved Equal"

- A generic design was provided but detailed with parts typically associated with one manufacturer.
- The Contractor used a different manufacturer which was approved, but the system lacked all the parts anticipated and required special design



Construction Challenges

Bridge Balancing

- Usually assume bridge is balanced at onset
- Span balance throughout stages of construction: strain gaging with calculations – still can result in final imbalance
- Understanding wind requirements (anemometer) in specifications can complicate testing

If significant counterweight material is expected, recommend using weight "pounds" as pay item unit

Construction Challenges

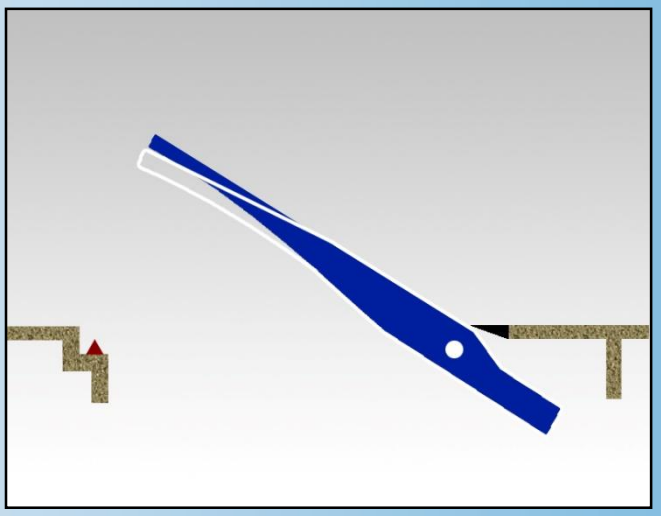
Other issues:

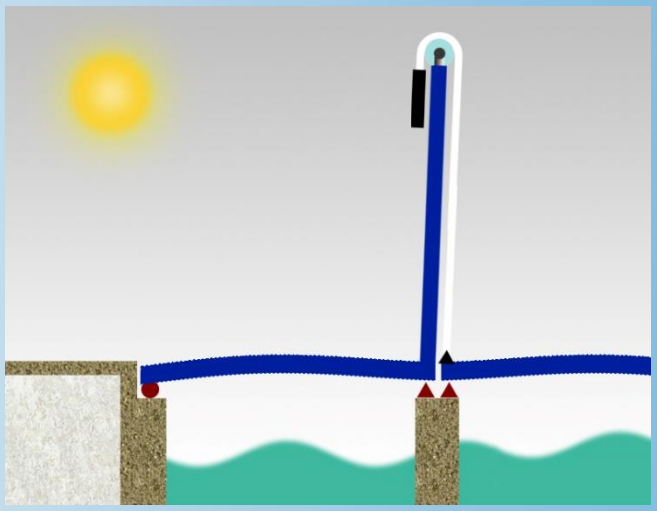
- Companies providing warranties for systems could be out of business
- Shaft tolerances/fit-up and initial condition
- Excessive corrosion from unused racks when bridge doesn't open fully – added maintenance cost
- Pack rust complicates installation of elements
- Limits of painting
- Confirm clearances to top-of-deck from stringers

Construction Challenges

Other issues:

- Temperature changes will affect the alignment & clearance associated with the movable span
  - As a bascule leaf warms up, the tip may deflect
  - As the bridge warms, the towers may lean in towards the movable span and reduce the operating clearances and possibly jam the span





Additional Reference Source

https://www.linkedin.com/groups/2120061

Thank you

Questions?

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