MOVABLE BRIDGES

Presented to:

NAAEA CONFERENCE
AT
HYATT REGENCY NORTH DALLAS

11/09/2018

Presented by:
Jamal Grainawi, SE, PE
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
Types of Movable Bridges

- Drawbridge
- **Bascule**
- Swing
- Vertical Lift
- Floating Bridges – Pontoon
- Submersible bridge
- Retracting Bridges
- Folding Bridges
- Curling Bridge
- Fan Bridge
- Tilt 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
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)
Types of Movable Bridges

- Drawbridge
- Bascule
- Swing
- **Vertical Lift**
- Floating Bridges – Pontoon
- Submersible bridge
- Retracting Bridges
- Folding Bridges
- Curling Bridge
- Fan Bridge
- Tilt Bridge
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)
Types of Movable Bridges

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

• Drawbridge
• Bascule
• Swing
• Vertical Lift
• Floating Bridges – Pontoon
• Submersible bridge
• Retracting Bridges
• Folding Bridges
• Curling Bridge
• Fan Bridge
• Tilt 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
Types of Movable Bridges

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

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

- Transporter Bridge
Movable Bridges

Other Types of Movable Bridges

- Transporter Bridge
Types of Bascule Bridges
Bascule Bridges

Trunnion Type
Bascule Bridges

Rolling-lift “Scherzer”
Bascule Bridges

• Single-leaf
• Double-leaf
• Double-Deck
Bascule Bridges

- Counterweight below Deck / Roadway
- Overhead Counterweight
Bascule Bridges

- Open Pier
- Closed Pier
Bascule Bridges

Different Drive Systems:

• Hydraulic systems
• Mechanical drive: electric motors with gears
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?

Jamal.Grainawi@wsp.com
Bascule Bridge Design
Bascule Bridge Design

Codes:


• 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:

\[
(W_{\text{leaf}}) \times (X_{\text{leaf}}) = (W_{\text{cwt}}) \times (X_{\text{cwt}})
\]

\[
(W_{\text{leaf}}) \times (Y_{\text{leaf}}) = (W_{\text{cwt}}) \times (Y_{\text{cwt}})
\]

\[
(W_{\text{leaf}}) + (W_{\text{cwt}}) = W_{\text{total}}
\]
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
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

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)
• Orthotropic
• Aluminum
• Sandwich Plate System
• Timber
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
• Aluminum
• Sandwich Plate System
• Timber
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 is 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
  • Exodermic / Concrete
  • FRP (Fiberglass Reinforced Polymer)

• Orthotropic
  • Aluminum
  • Sandwich Plate System
  • Timber
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
  - FRP (Fiberglass Reinforced Polymer)
  - Orthotropic
  - Aluminum
  - Sandwich Plate System
  - Timber
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:

• Open Steel Deck
• 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

Movable Bridge Engineers Network Group

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

Questions?

Jamal.Grainawi@wsp.com