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Support and Stabilization of Double-Leaf Bascule Bridges

James M. Phillips, III, PE
Hardesty & Hanover, LLC

Abstract

Double-leaf bascule bridges are a common movable bridge type in service in the United States. These structures require routine maintenance and periodic repair of the system and subsystems that support the bridge and stabilize it against undesirable motion and/or vibration. This paper presents the following with regard to double-leaf bascule bridge support and stabilization systems: fundamental principles; pertinent aspects of system design intent; identification of common problems and causes; and recommendations for adjustment and maintenance. These topics are presented with the goal of assisting owners and operators with best practices in bridge maintenance.

Key Words

balance; bascule; live load bearing; rolling-lift; span balance; span lock; tail lock; tail prop; tail stop; treads & tracks; trunnions

Introduction

The population of existing movable bridges comprises a diverse set of bridges types and an equal if not wider range of design configurations and system configurations. This paper discusses the support and stabilization systems of double-leaf bascule bridges - one of the major movable bridge types in service. It discusses the topic with regard to fundamental principles, pertinent aspects of system design intent, identification of common problems and causes, and recommendations for adjustment and maintenance. It is intended for application to existing bridges that are already constructed and in service, thereby assisting owners and operators with best practices in bridge maintenance.

For the most part, the subject is presented in general terms, such that it applies to most existing double-leaf bascule bridges. Specific details of particular bridge configurations and components are addressed to convey the intent of the discussion, recognizing that no one approach can cover the wide variety of bridge types and components that are in service. However, the fundamentals and details presented can be applied to a wide range of bridges, provided the specific configuration and details of each bridge are given due consideration. Furthermore, although the subject is double-leaf bascule bridges, many of the fundamentals are also applicable to single-leaf bascule bridges.

In addition to addressing only certain types of double-leaf bascule bridges, the scope of this work is limited primarily to the support and stabilization of bridges in the closed position. Drive machinery provides not only the motive force to operate a bascule leaf, but also the resistive forces to stabilize the leaf against unwanted rotation under overhauling wind loads during operation, and to hold the leaf against wind forces when the leaf is stopped in any open position. Other than touching upon some of the roles of drive machinery and how drive machinery interfaces with bridge seating, this paper does not address drive machinery in detail or stabilization of open bascule leaves. Similarly, it is beyond the scope of this paper to address the support system with regard to resistance of extreme event loads such as those resulting from earthquake or vessel impact.

Double-Leaf Bascule Bridge Support and Stabilization Systems

Bascule bridges are a type of movable bridge which rotates open about a horizontal axis to provide increased clearance underneath, typically for a navigation channel. Although there are many types of bridges that can be included in the bascule family, this paper focuses on those of the trunnion and rolling-lift configuration, which are commonly arranged as a pair of opposing leaves in a double-leaf bascule. The support and stabilization system for double-leaf bascule bridges includes the components, assemblies and subsystems that align, support and stabilize the bascule leaves under all conditions of loading. The primary functions of the support and stabilization system are summarized as follows:

a) Support the dead load of the movable span at rest and in motion

b) Support live load that crosses the movable span

c) Stabilize the movable span against dynamic response to maintain alignment of the deck with adjacent movable span(s) and fixed approach spans

d) Stabilize the movable span against operating, wind and seismic loads while open or in motion

e) Transfer loads from the movable span to the substructure

Typical Double-Leaf Bascule Bridge, Venice Avenue, Venice, FL

f) Facilitate proper seating of the bascule leaves

g) Align the deck and sidewalks of the movable span with those of the adjacent movable span(s) and fixed approach spans

The basic components of the system are the primary supports, live load bearings, locking mechanisms, span balance and machinery. Wear and deterioration can result in problems in the support and stabilization system evidenced by the following typical symptoms:

a) Improper alignment of deck and sidewalk joints

b) Hard seating of a leaf or rebound when seating

c) Inconsistent contact of fully seated limit switch(s)

d) Excessive noise or vibration under traffic

e) Difficulties in engaging or pulling locks

f) Excessive friction during operation - often evidenced by excessive power draw

g) Abnormal noise during operation emitting from the primary supports or locks

Double-Leaf Bascule Bridge Configurations

The Trunnion Bascule Bridge

Figure 1 shows the general arrangement of a double-leaf trunnion bascule, including identification of the support and stabilization system exclusive of the machinery. Span balance is represented in the schematic by the counterweight (CWT).
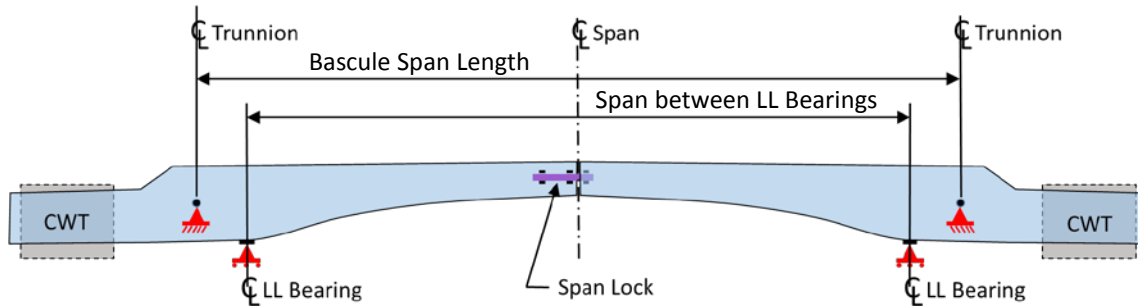
Figure 1 – Double-Leaf Trunnion Bascule Support and Stabilization Schematic

The following are the key elements of interest of this bridge type:

Bascule Pier: The bascule pier is the substructure that supports the bascule span and one end of the approach span (if present).

Bascule Span: The moving superstructure, including two opposing bascule leaves. Although the deck on the bascule span often extends back of the trunnion (towards the counterweight), the bascule span length is typically defined as the longitudinal distance between centerlines of trunnions. In some cases, the overall distance from the joint at the back of one bascule pier to that of the other is referred to as the bascule span length.

Bascule Leaf: One of the two opposing movable sections of the bridge, including the deck, structural framing, counterweight and appurtenances. The forward portion of the leaf, from the trunnion to the tip at the centerline between leaves, is commonly referred to as the toe section. Similarly, the portion of the leaf behind the centerline of trunnions, including the counterweight is referred to as the heel section.

Bascule Girders: The main longitudinal girders of the bascule leaf (movable) structure, typically steel plate girders or built-up riveted girders of variable depth, although welded box sections and truss members are not uncommon. Most bascule bridges are configured with a pair of bascule girders for each leaf, although some have three or more bascule girders. Bascule girders are typically connected to a system of steel framing, including floorbeams, stringers and cantilever brackets that support the bascule leaf deck.

Counterweight: The mass located on the heel side of the centerline of trunnion that is constructed for the purpose of counterbalancing the toe section of the bascule leaf.

Approach Span: The span adjacent to the movable span if present. Some bridges do not have approach spans where the bascule piers also serve as the bridge abutments.

Trunnions: The shafts that support the bascule leaf and about which the leaf rotates. Typically, each bascule leaf has a pair of trunnions, one supporting each of the bascule girders.

Live Load Bearings: Live load bearings (aka live load shoes) are bearings that prevent rotation of the bascule leaf due to unbalanced dead loads and dynamic loads that would otherwise produce rotation of the leaf(s) about the trunnion axis, including live loads, wind and seismic loads. Live load bearings may be located on the toe side of the trunnions to prevent the toe from moving downward (most common and referred to as Forward Live Load Bearings) or behind the trunnions on the heel section to prevent it from moving upward (referred to as Rear Live Load Bearings).

Photograph of a Typical Forward Live Load Bearing of a Double-Leaf Trunnion Bascule

Rack/Pinion: The final component of the machinery that imparts a moment about the trunnion axis to operate or hold the span when it is not supported on the live load bearings. For trunnion bascules, the racks are typically located on the main girders and centered about the trunnion axis. The drive machinery and rack pinion is typically mounted on the bascule pier. For hydraulic cylinder operated bridges the rack/pinion is replaced with a cylinder connection such as a clevis/clevis pin.

Span Lock: Also referred to as center locks, these devises provide a connection between the tips of the opposing bascule leaves at the center of the span that transfers live load shear across the center joint. They function to share live load between leaves and maintain alignment of the deck across the center joint. Span locks are typically located near the tips of the opposing main girders.

Tail Lock: Tail locks are located behind the trunnions and function to prevent the heel section from rotating under dynamic loading. Tail locks are only required if the leaf has a rear live load bearing or the rear joint is far enough behind the trunnions that live load on the heel would cause the toe to rotate upward.

Span Balance: The balance condition of a bascule leaf, commonly defined as the product of the weight of the leaf, W in kips, times the vector, L in feet, representing the position of the center of gravity of the leaf from the center of rotation. Span Balance is an element of the stabilization system.

The Rolling-Lift Bascule Bridge

Double-Leaf Rolling-Lift Bascule bridges are similar to trunnion bascules in configuration except rather than rotating about a fixed axis (trunnion) the bascule leaf rolls (rotates and translates) on tracks to open or close. Typically, each bascule girder is fitted with a curved tread mounted to the underside of the girder. Each tread is supported on a fixed flat track mounted to the bascule piers. A system of lugs and pockets or similar mechanism[1] is employed to maintain alignment of the tread and track throughout the limits of roll. **Figure 2** shows the general arrangement of a double-leaf rolling-lift bascule, including identification of the support and stabilization system.

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[1] Some rolling-lift spans have conical pintles and circular pockets for example.
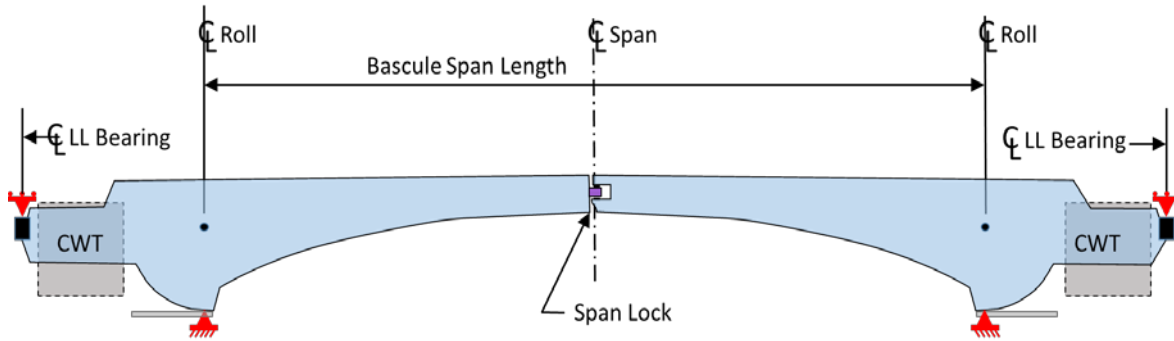
Figure 2 – Double-Leaf Rolling-Lift Bascule Support and Stabilization System Schematic

The following are the key elements of interest of this bridge type that differ from those of a trunnion bascule:

Bascule Span: The bascule span length is typical defined as the longitudinal distance between centerlines of roll with the bridge in the lowered position.

Bascule Leaf: One of the two opposing movable sections of the bridge, including the deck, structural framing, counterweight and appurtenances. For many rolling-lift spans, the drive machinery is mounted on the bascule leaf.

Treads: Curved plates, castings or forgings connected to the bottom of the main girders that support the bascule leaf and on which the leaf rolls. Often fabricated in sections and referred to as a segmental girder when considering the treads as an assembly with the main girder. Frequently equipped with pockets to accept the lugs built into the mating track.

Tracks: Flat plates, castings or forgings located on the bascule pier on which the bascule leaf treads roll.

Photograph of Tread (upper) with Pockets and Track (lower) with Lugs

Live Load Bearings: The live load bearings are commonly located above the heel section of the main girders, behind the center of roll to prevent it from moving upward. They are often mounted on the underside of an uplift girder or similar structural member anchored to the bascule pier.

Rack/Pinion: For rolling-lift bascules the machinery is typically located on the bascule leaf with the pinions centered on the center of roll. The rack is typically a flat rack, mounted horizontally to a fixed rack frame, secured to the bascule pier. Hydraulic cylinders may be attached at the center of roll or a location eccentric to the center of roll.

Span Lock: Jaw and diaphragm locks are common on rolling-lift bascules although lock bar systems are also used. Jaw and diaphragm locks do not have an operating mechanism (they are engaged and disengaged by operation of the bascule leaves) and do not prevent the bascule leaves from rotating.

Tail Lock: Tail locks are typically required on rolling-lift bascules that have jaw and diaphragm center locks to provide a positive means of preventing the leaves from opening.

Tail Stops: Tail stops are a type of tail lock, mounted behind the center of roll to prevent rotation of a bascule leaf when engaged. Where counterweights are subject to heavy live load, tail stops may pre-compress the bascule girder up against the rear live load bearing to firmly secure the heel section against rotation.

Jaw (left) and Diaphragm (right) Center Lock for Rolling-Lift Bridge

There are other bridge components sometimes present in both trunnion and rolling-lift bridges that may be considered part of the support and stabilization system, such as bumper blocks, buffer cylinders and centering devices.

Where provided, bumper blocks function to prevent over rotation of the bascule leaf beyond the limits of normal operation. The bumper block assembly typically consists of a pair of timber (or other hard, but compressible material) blocks, one mounted on the bascule leaf heel section and the other mounted on the bascule pier. The blocks are cut such that the contact surfaces make uniform contact when the leaf rotates past the full open position. In normal operation the leaf and pier mounted elements of the bumper blocks should not come into contact. They are typically set with a ½" nominal gap that only closes to contact if the leaf over rotates.

Many bascule bridges are equipped with buffer cylinders designed to cushion the seating of the leaf as it rotates toward the fully seated position. Buffers are most commonly pneumatic in type although hydraulic buffers are also used. Buffer cylinders are positioned on the bascule leaf on pivots so that the piston rod engages a strike plate as the leaf rotates into seating position. Contact forces the piston to retract and the piston motion causes a resisting, cushioning force proportional to the seating velocity. Most buffer cylinders have flow control valves that can be used to adjust the response of the buffer.

Centering devices are located at the tips of a pair of bascule leaves. They consist of a male and female part, one located on either side of the center joint. The two parts fit together as the leaves are lowered and function to position the tips horizontally relative to each other. Centering devices also transfer horizontal shear loads when a bridge is subjected to lateral seismic loads. Centering devices generally do not require routine maintenance or adjustment once properly installed.

System Performance and Design Intent

In examining the requirements for support and stabilization of bascule bridges a variety of service conditions must be considered from bridge operation and seating to vehicle and pedestrian loading. During normal bridge operation the support system must allow for leaf rotation with limited frictional resistance. Trunnions, track and tread assemblies, racks and pinions, locking mechanisms and centering

devices must all allow clearance for uninhibited motion, other than the friction associated with sliding and rolling action of machined parts in contact. Upon seating of the leaves in the closed position, the support and stabilization system must not impede the drive system from seating the leaves to obtain full contact with the live load bearings without bouncing or rebounding in such a manner as to hinder operation of electrical interlocks and/or mechanical locking devices. Bridge operation is performed under a variety of conditions including wind, temperature and differential temperature. The support and stabilization system must accommodate these varying conditions.

In normal service conditions, the support and stabilization system resists the dead load of the bascule leaf, live load due to vehicles and wind. Most of the loadings and support reactions are relatively simple in nature. Take the double-leaf trunnion bascule with forward live load bearing and span locks shown in **Figure 1** for example. In simplified form this double-leaf span consists of three spans, two back spans and a cantilevered center span with a central hinge (span lock). Live load on a bascule leaf forward of the live load bearings produces shear in the span lock and reactions at the supports including trunnions (negative reaction) and live load bearings (positive reaction). Live load applied to the deck between the trunnion and live load bearing produces reactions at the adjacent trunnion and live load bearing, but insignificant shear in the span lock (only that due to deformation of the main girder). Live load on the deck behind the trunnion produces a positive reaction at the trunnion and uplift at the live load bearings, for which they are incapable of resisting. This load condition exemplifies the need for a more comprehensive look at the stabilization system to include subsystems, components and span balance, or more correctly, span imbalance. Below is a functional description of these elements and a brief discussion of their design intent.

Primary Supports

Most bascule leaf dead load is supported at the primary supports, as well as a portion of the live load depending upon the configuration. During operation, other than the reaction at the operating machinery interface between the components attached to the fixed pier and movable leaf, the primary support carries the dead load and provides the mechanical restraint that guides the leaf as it is rotated.

Trunnion Assemblies: Trunnion assemblies allow rotation with limited frictional resistance while restricting horizontal translation. Typically, trunnion shafts have a shoulder that can bear against a bushing flange to prevent transverse (lateral) movement. However, trunnion assemblies must allow some transverse movement to avoid binding so a small gap is provided at the shoulder/bushing flange interface. Design plans and/or shop drawings often show the bushing/shoulder gap values at a nominal temperature and may show thermal expansion/contraction adjustments. These gaps are set during erection and rarely change. Routine inspections should confirm the gaps as on occasion debris may fill the gap or in extreme cases bushing

Typical Trunnion / Plain Trunnion Bearing Assembly – Port Ferdinand Bridge, Barbados, West Indies

wear or failure could create binding or excessive clearance. A typical clearance gap between the trunnion shaft shoulder and trunnion bushing flange is on the order of magnitude of 1/8" at each trunnion. In most cases bridges tend to one side, so it is not unusual to find no measurable gap at one trunnion and twice the per trunnion clearance at the other.

Trunnion shafts on a bascule leaf should be aligned with each other and the center of rotation of the leaf. Trunnion bearings should be set level with each other to avoid any strong tendency for the leaf to slide to one side. In general, bascule leaves tend to work their way into bearing on the shoulder of one trunnion. This condition is normal and not of concern unless the resulting action is sufficient to cause abnormally rapid wear of the trunnion bushing flange or binding. For the purpose of evaluating the span support and stabilization system, only a general assessment of trunnion alignment is necessary. There should be no evidence of binding during operation or under live load.

Treads and Tracks: Treads and tracks of rolling-lift bascules also have devices to restrain transverse movement, typically lugs and pockets or pintles and pockets. These confine motion to the longitudinal direction, guiding the leaf as it rotates if necessary. Additionally, these devices limit slippage on the rolling contact surface to assure rolling action and maintain proper indexing of the tread and track. As with trunnion assemblies, these devices have clearances to accommodate thermal expansion and contraction. Additional clearances are necessary to accommodate the kinematics of rotation. Great precision is required in aligning treads and tracks to restrain undesirable motion while accommodating both kinematic and thermal movements. Routine inspections should confirm there is no advancing wear on the treads or tracks, evidence of sliding action at the tread/track interface, or debris present that could foul operation. The gap between the lugs or pintles and their mating surfaces should be adequate to accommodate thermal expansion. For the purpose of assessing the span support and stabilization system, a detailed check of tread and track alignment is not warranted as long as there is no visual evidence of heavy wear or binding during operation or indication that the tread is sliding on the track.

Seating and Bridge Alignment

A primary function of the support and stabilization system is to align the movable span with adjacent movable span(s) and the fixed approach span. Design intent is for leaf positioning to be established by the primary supports and live load bearings. Lock mechanisms are generally not intended to establish alignment, only to preserve it. The primary supports – trunnion assemblies or tread and track assemblies – are designed and constructed to establish the plan location and elevation of the center of rotation of the bascule leaves. Once set, these points rarely require adjustment. With the center of rotation positioned, design intent is for the live load bearings to establish the angular position of the leaf, thereby aligning the leaf deck to the theoretical roadway profile.

Bascule spans are designed to match the deck and sidewalk surfaces on the movable span to the established profile grade and cross slope of the roadway. Many bascule bridges have specific geometry intended to simplify construction, including tangent (flat) profiles and/or no cross slope on the movable span (typically for bridges with open steel grid deck). Others are fit to match parabolic vertical curves common in roadway geometrics and/or include cross slope. Geometry is typically shown in the bridge plans. Once a bascule span is constructed, the as-built geometry, which may have small deviations from the intended design geometry, establishes the basis for setting or adjusting the live load bearings. Examples of common geometric deviations to be identified and considered include:

- Cross slope variations, particularly at the tips of the leaves
- Joint openings
- Vertical differences across joints

Drive Machinery

Drive machinery and the control systems that vary leaf speed and sequence braking play an important role in seating of bascule leaves. Like the role of drive machinery in stabilizing bascule leaves when they are not seated, a detailed discussion of drive machinery and associated control systems is beyond the scope of this paper. However, there are some basics relevant to this discussion.

The intent is for the drive system (machinery and associated controls) to rotate the bascule leaf into the seated position, providing the motive power to overcome external loads, friction and inertia. The general process is for the drive system to slow the leaf to a designated "creep speed" before the live load bearings make contact. Deceleration is performed by the drive, potentially with the assistance of brakes, buffer cylinders, or hydraulic cylinder cushions, all depending upon the configuration of the system and sequencing of the controls. Creep speed is typically established by design as 10 percent of full speed. However, the actual creep speed can vary as a function of drive adjustments, limit switch positions, wind, friction and temperature. If creep speed is too high, the bridge may seat hard, causing undesirable noise or vibration or even causing rebound. If creep speed is too low, the bridge may not seat fully or the fully closed limit switch may not engage consistently.

Many bascule bridges are configured with a drive seating feature referred to as "wind-up". This involves holding drive power (lowering torque) on after the fully closed limit switch is triggered to hold the bridge against the live load bearings for several seconds and load (wind up) torque in the drive machinery with the intent of eliminating rebound and holding the leaf tight against the live load bearings. A timer typically sets the brakes then turns off the drive power. Hydraulic cylinder bridges may be similarly equipped to sustain cylinder pressure for a few seconds. From a bridge support and stabilization perspective, a couple of notes on wind-up are worth noting:

a) Wind-up seating can be effective in eliminating rebound – thus the tolerances on creep speed and limit switch positioning can be more lenient and full seating more repeatable under various conditions

b) Wind-up is not a reliable means of maintaining full seating – traffic loading and associated dynamic effects will quickly overcome the holding provided by wind up

c) Wind-up can transmit dynamic traffic loading on the leaf to the drive machinery (whether or not wind-up is a good thing for the drive machinery is a topic for discussion elsewhere)

Live Load Bearings

Properly adjusted live load bearings, those that produce uniform contact under dead and live loads, are essential for bascule bridges to perform as intended. Small deviations in contact will not significantly alter the distribution of loads and stresses in the structural framing or produce significant out of plane bending in girders or trusses. However, small deviations can produce undesirable vibration, noise, and abnormal wear. Load shoes with gaps under all or part of the shoe under dead load only conditions tend to suffer from a form of abrasive fretting corrosion caused by repeated intermittent contact under traffic loading.

In general, live load bearings should be shimmed and aligned such that contact is no less than 80 percent across the width of the shoe under deal load only. If there is a gap between the load shoe and masonry (aka striker) plate it should not exceed 0.001" per foot of width. Masonry plates should be set level within 0.001" per foot in any direction.

By design intent, live load bearings provide only a positive reaction as is typically modeled by a roller. Live load bearings are not intended to retrain horizontal (lateral or longitudinal[2]) motion although some may be equipped with shear lugs for lateral seismic restraint. Live load bearings are also typically designed with a radius on the load shoe element to accommodate some rotation of the associated girder or truss[3].

Lock Mechanisms

Span Locks: Span locks are designed and constructed in a wide variety of configurations, each having specific requirements and tolerances for alignment and inspection. Addressing all types is beyond the scope of this paper. However, there are some fundamental principles common to most all types with regard to span support and stabilization. Lock effectiveness in transferring shear across the center joint is not absolute and cannot be due to clearances in the lock system and flexibility of the lock components and supports. Recent studies[4] have demonstrated that even heavily worn span locks that result in excessive differential deflection across the center joint, still operate effectively enough to transfer more than 90 percent of shear. However, as with other elements of the span support and stabilization system, span lock wear becomes detrimental to the system long before the loss of effective shear transfer becomes a concern. Worn lock systems lead to an increase in noise and vibration observed by travelers and pedestrians which, even if not detrimental to the performance of the locks, does not convey a sense of safety or good maintenance practice to the general public. Worn lock components can also cause irregularities in limit switch performance.

Tail Locks & Tail Stops: Tail locks and tail stops are devices located at the heel of the bascule leaf, behind the center of rotation, to block movement of the bascule leaf. The terms tail locks and tail stops are often used to describe a family of devices with various means of operation and function. For the purpose of this paper and to better categorize this family of devices, the following definitions will be used, including the introduction of "Tail Stop" as a new term:

Tail Lock: A tail lock is a span lock that is positioned behind the center of rotation whose function is to block movement of the bascule leaf from rotating in either direction due to live loads. In operation a tail lock engages without resisting the dead load or dead load imbalance of the span. The most common type of tail lock is a lock bar driven between a guide and receiver to "pin" the leaf against rotation.

Tail Stop: Like a tail lock, a tail stop is positioned behind the center of rotation. A tail stop functions to block movement of the bascule leaf from rotating open due to live loads. In operation a tail stop engages without resisting the dead load or dead load imbalance of the span. The most common type of tail lock is a strut that is mounted on a pivot anchored to the bascule pier and that is rotated into position below a load shoe mounted to the bascule leaf.

Tail Prop: A tail prop is positioned behind the center of rotation and functions to secure the heel of the leaf tightly against the rear live load bearing and block the span from rotating open. The significant difference between a tail prop and a tail stop is that the tail prop is preloaded as it is driven into

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[2] Live load bearings are generally free to slide longitudinally to accommodate thermal movements

[3] This is particularly true for forward live load bearings which are located in a zone of the girder or truss subjected to significant bending moments.

[4] AASHTO Span Lock Design Study, AS 13-0014 for the Support of the HSCOBS Technical Committee on Moveable Bridges (T-8)

position. Most tail props include a compound strut mechanism with a hinge, knuckle or cam that preloads the strut as it is rotated into position and locks it in place by rotating slightly over center.

Lock Functions

AASHTO Movable[5] states the following within Article 6.4.2, Aligning and Locking of Movable Span:

> *"Movable bridges shall be equipped with span locks or other suitable mechanisms to accurately align the span ends to the approach roadway, both horizontally and vertically, and to secure the movable span in the closed position so that it cannot be displaced either horizontally or vertically under the action of traffic or other conditions of service. Span locks shall be designed so that they cannot be engaged unless the movable portions of the span are within ½ in. of the proper position."*

Reading the first part of this article may be interpreted to state that locks are intended to align the movable span. However, the full article and commentary must be considered. The commentary for this Article, C6.4.2 states:

> *"For a double leaf bascule, the two leaves must be aligned vertically within ½ in. relative to each other for the locks to be driven."*

Here the code implies that the leaves must already be aligned (by the live load bearings) to within ½" before the locks can be driven. The key to understanding this is to examine the other functions of locks, namely "*so that [the movable span] cannot be displaced… under the action of traffic or other conditions of service.*" This requires two functions of the locks: a) to provide a physical restraint; and b) to enable fail-safe interlocking in concert with the lock limit switches and control system. Therefore, rather than functioning to align the movable span, locks are generally designed to maintain alignment achieved by seating the leaf against the live load bearings.

Span Balance

A key element in supporting and securing double-leaf bascule bridges is span balance, specifically the amount and orientation of the imbalance. There are a variety of methods used to establish the terminology for span balance. For this discussion, the following terms are used with reference to **Figure 3**:

Alpha:	The angle between horizontal and the center of gravity of the leaf, measured positive counterclockwise from horizontal
WLcos(Alpha):	The dead load imbalance with the leaf in the closed position
WL:	The vector product of the leaf weight, W, and the distance from the center of rotation to the center of gravity of the leaf, L
Average Friction:	The average friction in the system. When determined by strain gauge balance testing average friction is the friction between the location of the measured strain (e.g. a shaft) or pressure (e.g. a cylinder or hydraulic motor) and the leaf support – often reported as average trunnion friction on trunnion bascules even though it may also include the frictional losses at the rack/pinion and/or other machinery downstream from the gauges

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[5] AASHTO (American Association of State Highway and Transportation Officials)(2007) AASHTO LRFD Movable Highway Bridge Design Specifications, 2th edn. AASHTO, Washington, DC
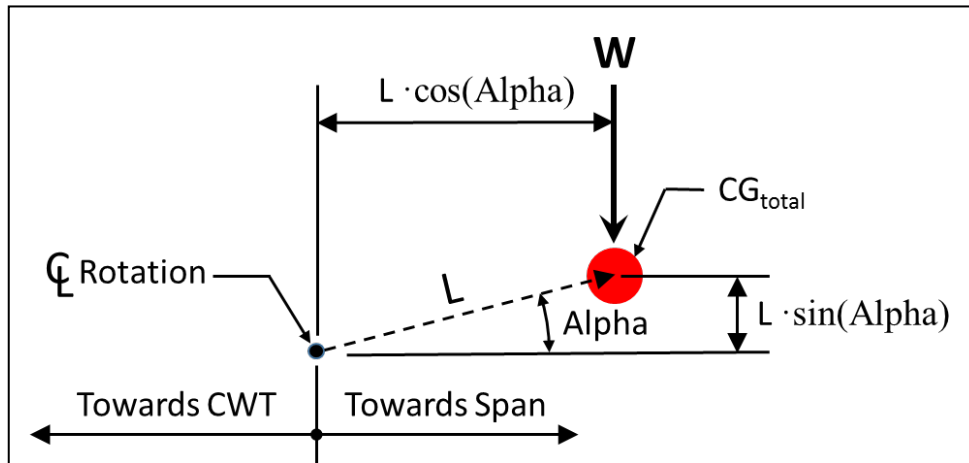
Figure 3 – Bascule Span Balance Diagram and Terminology

AASHTO Movable, Article 1.5 Balance and Counterweights, includes the following statements regarding balance:

1.5.1 – "*As near practical, the counterweights shall be sufficient to balance the movable span and its attachments in any position, except that there shall be **small positive[6]** dead load reactions, specified by the designer, at the supports when the bridge is seated.*"

C1.5.1 – "*If a bascule bridge has a roadway break behind the trunnion, i.e. toward the counterweight, the span imbalance should be greater than live loading cases that would tend to cause uplift, but shall not be less than the general cases below.*"

"*For all bascule bridges, the movable leaves should be balanced such that the center of gravity with the span fully seated is located towards the channel at an angle no greater than 20 degrees above or below a horizontal line passing through the trunnion.*"

"*Bascule bridge operated hydraulically, especially with cylinders, should be balanced such that they are span heavy in all positions.*"

"*For single leaf bascules, the equivalent downward reaction at the toe should be 1,000 lb. per bascule girder with the leaf fully seated.*"

"*For double leaf bascules, the equivalent downward reaction at the toe should be 1,500 lb. per bascule girder with the leaf fully seated.*"

The above approach maintains a positive (span heavy) condition throughout operation. This reduces the variability in load direction that has, in some cases, been known to create oscillations of the bridge during operation, especially in hydraulic cylinder driven bridges. It also makes emergency manual lowering of the leaf easier and provides opportunity to drift a leaf down without power. The general drawback to this approach is that the operating loads are nearly always in the same direction, thus wearing only one side of the drive system gearing – a condition that is not a concern for hydraulic cylinder bridges.

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[6] AASHTO does not specify the magnitude of the dead load reactions or a tolerance.

An alternative to the above approach is commonly exercised within the movable bridge community. Some designers and owners specify a balance condition whereby the CG goes over center as the leaf is raised. The idea behind this concept is to balance loading on the drive machinery – in effect, to drive the bridge halfway up while retarding motion for the other half of the operation and vice versa for the lowering operation. In theory this utilizes more gear contact surfaces and extends the life of the gearing. This approach addresses the fact that prior to LRFD, movable bridge gearing was generally designed for strength and not durability. Since the institution of LRFD movable bridge, gearing has been designed for both strength and durability. Therefore, a key benefit of this method is somewhat less significant for newer bridges or bridges with newer machinery.

For the alternative approach Alpha is generally set at approximately one half of the full opening angle from 90 degrees. For example, a bridge that rotates 76 degrees would be balanced for Alpha equals 52 degrees (90 – 76/2). Under these conditions the tolerance of the CG position becomes more critical. For example the difference in imbalance for a given WL at 52 degrees plus or minus 10 degrees is 58 percent while at zero degrees plus or minus 20 degrees is only 6 percent.

A similar approach to span balance is established by the Florida Department of Transportation (FDOT). The following are excerpts from the FDOT Structures Design Guidelines, Article 8.6.3 stipulating requirements for balancing bascule bridges:

Design mechanical drive system bridges to meet following requirements:

a) The center of gravity is forward (toe heavy) of the trunnion and is located at an angle (Alpha) 20 degrees to 50 degrees above a horizontal line passing through the center of trunnion with the leaf in the down position

b) Ensure the leaf is tail (counterweight) heavy in the fully open position

c) Design both single and double-leaf bascules for a leaf heavy out of balance condition that will produce an equivalent force of two kips minimum at the tip of the leaf when the leaf is down.

d) Ensure that the maximum unbalance force is four kips at the tip of the leaf when the leaf is in the down position

e) If hydraulics (cylinder drives) are specified, ensure the balance is such that the center of gravity is forward (leaf heavy) of the trunnion throughout the operating (opening) angle

Significant is that AASHTO Movable does not specify tolerances for the equivalent reaction the toe of the bascule girder. What is not stated in AASHTO Movable, and yet is very important from a support and stability perspective, is that the general intent is for the imbalance to be sufficient to firmly seat the leaf. To firmly seat the leaf and have it remain firmly seated under dynamic loading, the imbalance should be sufficient to overcome the static frictional resistances that could otherwise hold the leaf from full contact with the live load bearings[7]. This is generally covered by the recommended span imbalance, but not implicit in AASHTO Movable. As an example, consider the following typical double-leaf, trunnion bascule bridge featuring an open steel grid deck:

Span Length: 140 feet between centerlines of trunnions, 70-foot trunnion to tip of bascule leaf

Width: 43 feet wide, out to out

Mass: 880 kips (total weight of one leaf)

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[7] See discussion below of lightweight movable span vs the trend for heavier movable spans.

Trunnion: 20 inch diameter (0.83' radius) journal; plain bronze bushing; static coefficient of friction of 0.18[8]

The calculated static frictional resistance of the trunnions is 0.83' x 880k x 0.18 = 131 kip·ft. The minimum recommended imbalance per AASHTO Movable (C1.5.1) is 70 feet x 1.5 kips x 2 girders = 210 kip·ft, sufficiently more than the minimum needed to overcome the calculated static friction. In other words, if the bascule leaf were to be moved off of firm seating for any reason, it would tend to sit back down firmly without assistance from the drive machinery.

Balance measurement is typically performed by the strain gauge method. This involves attaching strain gauges to a shaft of the drive machinery and recording the torque required to raise and lower a bascule leaf as a function of the angular position of the leaf. Analysis of this data can yield the span imbalance in terms of the unbalanced moment and position of the center of gravity of the bascule leaf as well as the average friction in the system. A similar approach, using pressure transducers, can be applied to determine the balance condition of a bridge operated by hydraulic cylinders or hydraulic motors. Using one of the above methods produces the data needed for evaluation of span balance and span balance adjustments, including WLcos(Alpha), WL, Alpha, and Average Friction.

In general, instrumentation and data analysis does not yield the weight of the leaf, W, or the distance L. These values are not necessary for evaluation of the support and stabilization system, but are useful when available and can often be found in existing bridge plans or shop drawings. For reference, it is noted that values of L are generally very small in comparison to leaf dimensions. For the previous example bridge with a weight of 880 kips (W) and an imbalance of 210 kip-ft (WLcos(Alpha)) the value of L would be on the order of magnitude of 3 inches depending upon Alpha. If the leaf CG is located at the same elevation as the center of rotation, in other words with Alpha equal to zero, L is 2.86". However, if the CG is at an angle of 35 degrees above horizontal, L is equal to 3.50". This leads to two important considerations. First, span balance is sensitive to the CG location. Second, the CG location is sensitive to small changes in Alpha. Consider the following example:

Leaf Weight, W = 880 kips

Angle of Leaf Rotation = 76°

Alpha is 50 degrees (i.e. the bridge is designed for the CG to go over center as the leaf rotates

WLcos(Alpha) = 300 kip-ft

From this we can determine that the CG is located at an offset of x = 4.09" and y = 4.87". We can also solve for the effective imbalance with the span fully rotated, WLcos(Alpha + 75°) = -268 kip-ft.

The owner desires an imbalance of no more than 210 kip-ft, so adds blocks to the counterweight that have an equivalent moment of 90 kip-ft, with the blocks located at the same elevation as the center of rotation. WLcos(Alpha) is therefore changed to 210 kip-ft, but Alpha is also changed from 50° to 59.6°. With the leaf at full open the imbalance is now -291 kip-ft. The result of reducing the imbalance with the leaf closed is that the imbalance increased with the leaf full open. This is not to say that the bridge could not be balanced properly, but to do so will require both vertical and horizontal adjustment of ballast. The adjustments can be calculated by considering the vector WL. The horizontal adjustment required is -90 kip-ft. Therefore, the vertical adjustment required is 90 x tan(50°), or -107 kip-ft if Alpha is to remain at 50°. The total weight (ballast) to be added to the counterweight must be determined by examining

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[8] 0.18 is the AASHTO specified coefficient of static friction for use in design, actual values can vary but are generally less than this value.

the available counterweight pockets. A common problem is that the center of gravity of the counterweight pockets is often located at a greater horizontal offset from the center of rotation than vertical offset. If the pocket is located low rather than well back of the center of rotation, ballast added or removed at this pocket will not produce as much imbalance as a pocket located at a greater horizontal offset, thus more ballast will be needed for a given correction of WLcos(Alpha).

In contrast, if the bridge were designed for the CG to stay on the toe side of rotation throughout, for example Alpha of 20° (x = 4.09"; y = 1.49"; WLcos(Alpha + 75° = -29 kip-ft), then adding the same ballast would change Alpha from 20 degrees to 27.5 degrees and WLcos(Alpha + 75°) would change to -51 kip-ft. In other words, the adjustments for this CG configuration are less sensitive to changes in WLcos(Alpha). Furthermore, the counterweight pockets can be located to the back of the counterweight where they are more effective.

In lieu of strain gauge span balance testing, other less accurate but useful methods can be used to establish the general nature and acceptability of span imbalance with regard to span support and stabilization. Chart recordings of motor amperage draw provide similar information to drive machinery torque, but with less accuracy and certainty. This is especially true for modern solid state drives, whose torque output is not directly proportional to motor amperage as is generally the case for resistance controlled wound rotor motors or direct current motors.

A simple yet effective means to determine if a bascule leaf's imbalance is adequate for the purpose of support and stabilization is to perform a drift test(s). Drift tests can cut to the chase and provide just what is needed for this purpose. After all, what is important from a support and stability perspective is whether or not the leaf stays firmly seated on its supports. As noted above, to be firmly seated the imbalance must be sufficient to overcome the static frictional resistances that could otherwise hold the leaf from full contact with the live load bearings.

Before proceeding with this discussion, it is important to note that there are limitations to the above assumptions. The vast majority of bascule bridges that are in service fall into one of the following categories for which drift testing is effective:

- Bridges with lightweight deck systems, such as open steel grid decking,

- Trunnion bascule bridges with anti-friction roller bearings (regardless of deck type),

- Rolling-lift bridges (regardless of deck type).

Trunnion bascules with relatively heavy deck systems, such as concrete filled grid or Exodermic® Deck that have plain trunnion bearings (bronze sleeve bearings) are likely to have more static friction resistance to rotation than can be overcome by traditional imbalance. Therefore, these bridges will not drift in most cases. As reference, the ratio of starting friction to span imbalance is shown below in Chart A for a set of 32 representative bascule bridges. Span Balance (i.e. imbalance) per AASHTO Movable is shown by the line of blue data points. Bridges plotted above the blue data points have starting friction (primary supports only, ignoring machinery) that exceeds the design span imbalance. As can be seen, only bridges with solid decks and plain bearing fall in this category.

Chart A

Starting Friction vs Span Imbalance
for a Set of Representative Bascule Bridges
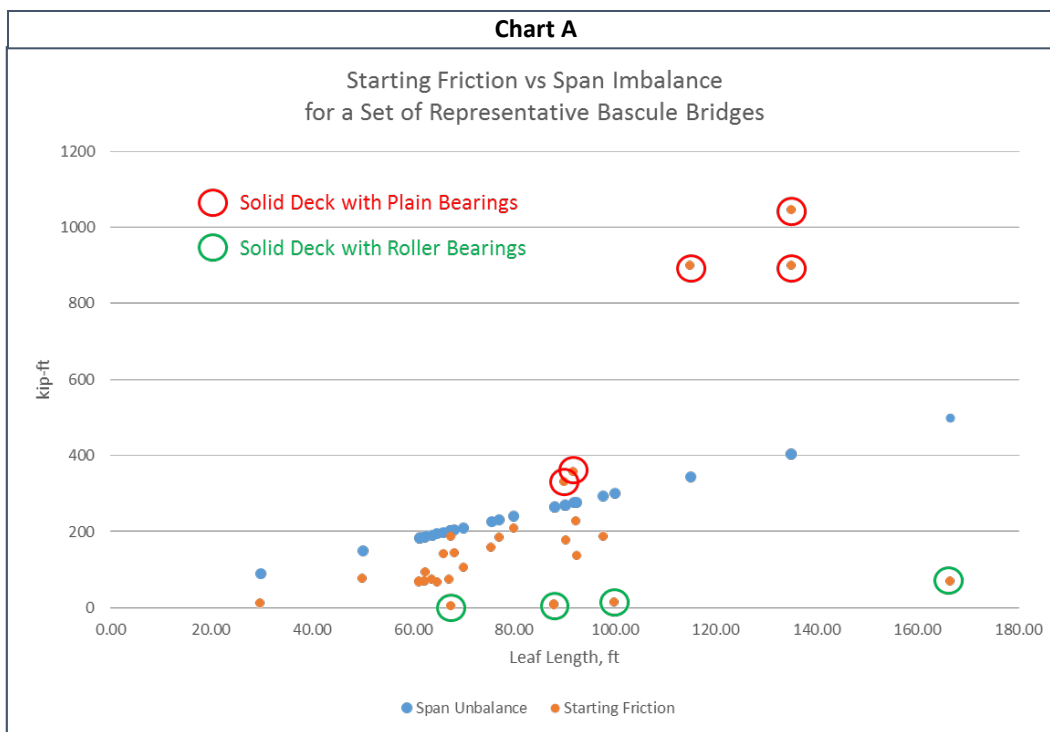
Like other span balance tests drifts tests are best performed in the lack of wind or other weather conditions. Raise the leaf to the fully open position and secure it with the brakes. Disconnect power from the motors. Confirm that the brakes hold the span securely in position. Release the machinery brake. Confirm that the machinery brake holds the span. If not, discontinue drift tests and report the bridge balance and/or brakes are not properly functioning and require immediate attention. Otherwise proceed with the drift tests. Manually release the motor brake and observe if the leaf rotates and if so in which direction, open or close.

Move the leaf incrementally to a series of positions and repeat the test making sure to stop the leaf at each position and confirm the ability of the motor brake to hold the load prior to releasing the brake to determine if the leaf rotates and in which direction. For best results, test for drift at full open, at a position with the live load bearings one foot from contact and at three or more positions in between or as necessary to determine the leaf angle best representing a balanced condition. This angle is halfway between the angles for which the bridge just rotates open from a stopped condition and that which just rotates closed from a stopped position. Alpha can be estimated by subtracting the angle best representing a balanced condition from 90 degrees.

If the span imbalance is not sufficient to seat the leaf, corrective adjustments should be made. Bascule bridges are typically designed with pockets in the counterweights partially filled with balance blocks or some other form of ballast that can be moved, removed, or supplemented to adjust the span balance. Calculating the required adjustments requires the following:

- The existing span balance condition, generally determined in the form WL (the product of the span weight and distance from the center of rotation to the center of gravity, reported in kip·ft) and Alpha, the angle between a horizontal line starting at the center of rotation and projecting towards the channel and a line from the center of rotation to the location of the center of gravity, reported in degrees

- The size and location of the counterweight pockets including the position of the pockets relative to the center of rotation of the leaf (represented by x and y the distance behind and above the center or rotation respectively)

- The weight, number and position of existing balance blocks, again referenced to the center of rotation

Following span balance adjustments, check the balance again to confirm that the adjustments produced the desired results

Trouble Shooting the Support and Stabilization System

The following are recommended basic steps for inspection and evaluation of the support and stabilization system. These are not intended to cover the full in-depth inspection of all of the relevant components, as each system has specific, or even unique aspects that are beyond the scope of this paper. Rather, these steps are a guide to establishing the root cause of various symptoms and determining a course of corrective action.

1. Where available obtain copies of existing bridge as-built plans, recent inspection reports, and span balance reports. Relevant information includes:

   - Deck profile geometry

   - Leaf weight

   - Counterweight pocket locations

   - Primary Support, Lock and Live Load Bearing details

2. Interview maintenance and operation personnel familiar with the bridge to find out if there are ongoing or intermittent issues that could be related to the support and stabilization system.

3. Observe the bridge under normal traffic. Note the ambient conditions including the position of the sun relative to the bridge, in particular if the sun tends to warm one girder more than the other. If it is suspected that differential temperatures are causing periodic functional issues observe the bridge at different times of the day (or even different times of the year). Symptoms of differential thermal deformations include irregular seating, live load bearing contact or lock issues. These may be caused because one or more girders are deforming (cambering) differently than the others.

   Check primary supports for any signs of unusual wear or binding. Confirm that contact surfaces are clear and free of debris. For plain trunnion bearings confirm that the bushings are secure in the housings and free of cracks. Bridges with bronze sleeve bearings should exhibit a small horizontal gap between the bushing flanges and the trust surfaces of the trunnion. There should be no evidence of cracks in the bushings. For treads and tracks, note any indications of recent wear on lugs or pintles and their mating surfaces. The track should not be heavily lubricated, in particular, the rolling contact surface. Lubrication of the rolling surface is only for the purpose of protecting against corrosion. Heavy lubrication tends to attract and retain debris which can damage contact surfaces.

   Check for any gaps between the live load shoes and bearing plates. Measure gaps with a feeler gauge. Determine if the contact between the live load shoes and bearing plates is uniform. If not, measure and record the extent of full contact and size of any gaps using feeler gauges.

   Measure the relative deflection between the tips of the bascule leaves across the center joint as trucks cross the span. Take measurements at the center and both sides, as close to the center locks

as practical. Use a straight edge and machinist's scale to measure the deflection, noting that visual observations are often deceiving.

Check the joints in the roadway deck and sidewalks, measure and record any unusual vertical (more than 1/8") steps or horizontal gaps (less than 1/4" or more than 1/2" for sidewalks, less than ½" or more than 1-1/2" for roadway). Note any evidence of joint binding or contact.

4. Observe the bridge during operation of the locking mechanisms.

Pull and drive tail stops, tail locks and/or span locks. Record any evidence of binding or difficult operation (actuator straining). Observe and record any leaf movement associated with lock operation - best observed at the center joint and live load bearings. In general, the leaf should not move as locks are operated. Measure any movement observed at the live load bearings. Movement may indicate that either the leaf was not firmly seated on the live load bearings or the locks are not properly aligned.

5. Observe the bridge during operation and seating.

Observe primary supports throughout a full operation. Note any unusual noise, vibration or evidence of potential interference or binding. Confirm that each leaf rotates to its full open position.

With the leaf raised, inspect the contact surfaces of the live load bearing assemblies and tread and track assemblies for rolling-lift bridges. Check for signs of advanced or abnormal wear. These are often evidenced by worn indentations on the flat surfaces or flat spots on curved surfaces. These may be accompanied by corrosion residue, evidence of fretting.

Seat the bridge and check the live load bearings for firm contact prior to actuating locking mechanisms. Confirm live load bearing contact initially with the span locks (and tail locks or tail stops if they exist) disengaged. This test is to confirm the alignment of the shoes and plates in a dead load (span imbalance) condition only, without the influence of the locks.

Observe if the drive system has control of the seating operating such that creep speed is slow enough to avoid rebound, but fast enough to fully seat the leaf. Observe if the seating process involves wind-up.

For bridges equipped with Tail Props, engage the props, confirm that the action firmly secures the associated live load bearing contact and preloads the prop. Observe if the leaf moves during engagement.

Using an amp meter, observe the motor amperage during constant velocity (ignore amperage during acceleration, deceleration and seating) and compare it to Full Load Amps (FLA).

6. Check the bumper blocks if present

Check the bumper blocks for integrity and proper clearance. Timber blocks and anchor bolts are subject to environmental deterioration. Timber should be solid and have no more than limited deterioration. With the leaf full open, and stopped by the drive system, there should be a small, uniform gap between the contact surfaces. Unless otherwise shown in the bridge specific information, a clearance of no less than 1/2" and no more than 1.5" is typical. The blocks should not make contact during normal operation.

7. Check the buffer cylinders if present

Detailed inspection of buffer cylinders requires knowledge of the specific details of the system. For the purpose of evaluating the leaf support and stabilization system, confirm that the buffers retract on seating and fully extend as the leaf is raised. Confirm that the buffers generate resistance as they

are contracted. If there are pressure gauges they should show a rise in pressure as soon as the rod begins to move into the cylinder. Buffers should not prevent the leaf from seating or cause it to rebound as it seats.

8. Assess Span Balance

If the leaves seat firmly on the live load bearings without assistance from the locking mechanisms, seating is smooth and without excessive impact or rebound, and the motors do not strain (motor amperage remains below 50% of FLA) during constant velocity to raise the leaves, span balance is likely to be in the acceptable range. If not, perform drift testing. If drift tests are not conclusive, recommend span balance measurement by the strain gauge method.

In most cases excess span imbalance, unless extreme, is not detrimental to the support and stabilization system or its performance. Excess imbalance can be detrimental to the drive machinery, motors and drives and even cause hard seating in some cases. As long as the span imbalance does not cause the motors to draw more than 100 percent FLT under constant velocity operation and the leaf can be held by the motor brakes alone, it is unlikely to have a negative impact on the support system.

As evidence of the above, data was collected for a number of representative bascule bridges. The data included the span configuration, trunnion bearing type and configuration or tread and track roll radius, drive motor and motor brake parameters. Chart B presents a comparison of data from a set

Chart B - Span Imbalance vs FLT for a Set of 21 Representative Bridges
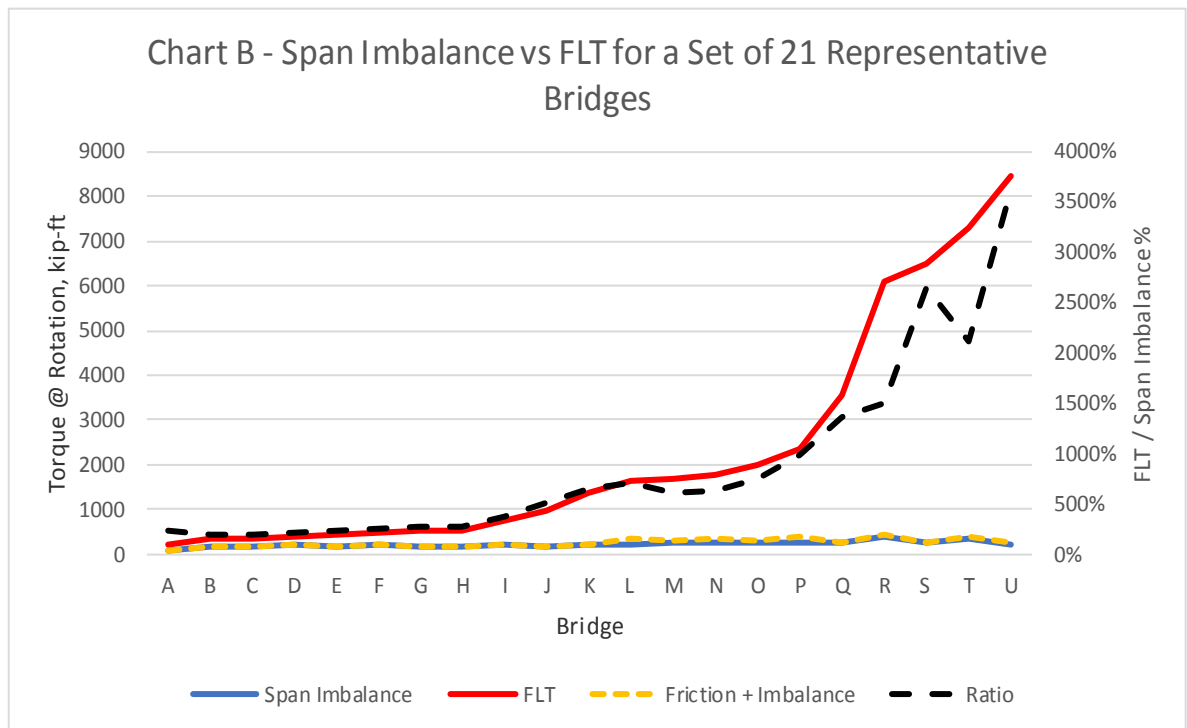
of 21 of the bridges (labeled A thru U), comparing the following:

a) Span Imbalance – calculated per AASHTO Movable, shown as a moment about the center of rotation in kip-ft

b) Motor Full Load Torque – shown as the effective torque about the center of rotation in kip-ft

    c) Running Friction – running frictional resistance of the primary support, exclusive of the drive machinery, shown combined with Span Imbalance as a moment about the center of rotation in kip-ft

    d) Ratio – the ratio of FLT/Span Imbalance in percentage

The bridges are sorted by FLT, smallest (7.5 HP) to the left, largest (150 HP) to the right. This data shows that FLT capacity is always at least twice the resistance of the span imbalance.

Corrective Action

Most common support and stabilization deficiencies can be corrected by maintenance staff through a series of adjustments to span balance, live load bearings and locking mechanisms. What is critical is that the adjustments be made in the proper sequence and with consideration of the entire system. Making adjustments to one element without regard for the whole system can be detrimental and often leads to increased problems.

If there is any evidence of unusual vibration or binding in the trunnion or track/tread assemblies, it may warrant further investigation, including detailed measurement of alignment.

A holistic approach to adjusting the support and stabilization system that will address most common deficiencies is presented below. These do not include corrective action for more severe issues or those associated with component failures in the primary supports or locking mechanisms which are beyond the scope of this paper and require additional investigation, analysis and design specific to the details. If misalignment is identified in the trunnion or track/tread assemblies, these should be corrected before proceeding with the program outlined below.

Span Balance Adjustment

The discussion and recommendations herein are limited to bridges that are in service. While the recommended span support and stabilization system adjustment procedure can be applied to newly constructed or rehabilitated bridges, there are differences that must be carefully considered, most notably the vertical position of balance adjustment. Assuming a leaf was properly balanced following construction or rehabilitation, small adjustments in balance can generally be made with little concern for the vertical position of the ballast added or removed. If major changes in balance are needed or significant vertical adjustment is required then strain gauge balancing should be used in lieu of drift testing. It is not the intent or recommendation to change the design intent of an existing bridge's balance arbitrarily. Changing the design intent may involve significant reconfiguration of counterweight ballast or even modification of the counterweight.

Ideally, span balance adjustment is made in concert with a series of span balance measurements conducted by the strain gauge (or pressure transducer) method. However, if this method is not available, the drift test method can be used.

Adjust each existing bascule leaf to the specific requirements of that particular design or owner specific requirements. Where a specifics balance intent is not available adjust the balance of each leaf to the following:

a) Trunnion Bascule with Electro-mechanical or hydraulic motor drive:

    i. Imbalance with leaf lowered = equivalent of 3.0 kips at the tip of each leaf; tolerance of plus 20%, minus 0%

    ii. Center of gravity at Alpha = zero degrees with a tolerance of plus or minus 20 degrees

b) Trunnion Bascule with Hydraulic cylinder drive:

    i. Imbalance with leaf lowered = equivalent of 3.0 kips at the tip of each leaf; tolerance of plus 50%, minus 0%

    ii. Center of gravity at Alpha = zero degrees with a tolerance of plus or minus 20 degrees

c) Rolling-Lift Bascule with Electro-mechanical, hydraulic motor or hydraulic cylinder drive:

    i. Imbalance with leaf lowered = equivalent of 3.0 kips at the tip of each leaf plus 20%, minus 0%

    ii. Center of gravity at Alpha = 90 degrees minus one half the operating angle plus zero, minus 20 degrees

A direct solution to determining what adjustments in ballast will produce the desired span balance condition is available through simple vector addition. With the existing and desired WL vectors known (WL and Alpha) simple subtraction will yield the order of magnitude change that is necessary. However, in practice determining the number of ballast blocks to add or remove is usually done with a simple spreadsheet or hand calculation. This is because the options available are constrained by the location and position of existing ballast and available counterweight pocket space.

A general rule of thumb that may be useful in the field if detailed existing bridge dimensional or balance information is not available, is that a pound applied at the tip of the leaf is equivalent to 4 pounds of counterweight adjustment. For example, a 200 pound person standing at the leaf tip is the same as removing 800 pounds of ballast from the counterweight. In practical application consider a case where during drift testing that a leaf does not seat under its current imbalance. If a person (or more) walk out to the tip and that is sufficient to cause the leaf to seat then the above ratio can be used to calculate a quick approximate adjustment in ballast.

Live Load Bearing Adjustment

After the span balance has been adjusted to within acceptable parameters, adjust the live load bearings to position each leaf at the proper full closed angle, align the adjacent leaves at the tips, and achieve full, uniform contact of the live load bearings. Live load bearings set the angle of rotation of a leaf when fully closed. The desired leaf position is such that the profile grade of the deck is as designed. Primarily this involves setting the deck at the tips of the leaves to the correct elevation. However, the as-built geometry of the bridge may warrant slight deviations from the ideal tip elevation to best fit the various joints in the roadway and sidewalk, if present. Generally, each live load bearing includes a shoe attached to the bascule leaf by bolts, either high strength or preferably turned bolts. Shims are provided between the load shoe and the girder or truss for adjustment. In most cases the shoe is bolted directly to the girder flange which has a milled bearing surface. In other cases the shoe is attached to a casting, weldment or plate connected to the girder or truss. If necessary to adjust the slope of the shoe to obtain full contact with the masonry plate or bearing plate on the fixed structure, use a mill plate or tapered shims.

Once a leaf is set to best fit the various deck joints and the shoe contact is optimized, adjust the pair of live load bearings on each leaf to balance the load between them using the following procedure (arbitrarily assigning the live load bearings designations LLB-A and LLB-B for descriptive purposes):

1. Raise the leaf and insert a steel or brass shim of known thickness in the range of 1/32" to 1/16" between the load shoe and bearing plate at LLB-A. Lower the leaf and measure and record the clearance between the load shoe and bearing plate at LLB-B using feeler gauges. A taper gauge is a good option for these measurements. If no gap exists, repeat with a thicker shim. If the bridge

lowering sequence involves winding up the motor to hold the leaf down, complete the operation and release the brakes before taking measurements. Measure the gap at the smallest point at the ends and center of the load shoe to the nearest 0.001". Average the measurements and record as CL-B.

2.   Remove the shim at LLB-A and install the same shim or thickness shim between the load shoe and bearing plate at LLB-B. Lower the leaf, measure the clearances at LLB-A and record the average as CL-A.

3.   Calculate Delta, one half the difference in the two average clearances (CL-B – CL-A)/2. Adjust the shims at the Live Load Bearing with the larger clearance by adding a shim of thickness Delta (or alternatively remove shims of thickness Delta from the Live Load Bearing with the lesser clearance.

4.   Repeat the above process until Delta is less than 0.005".

Lock Adjustment

Once the live load bearings are adjusted to full contact with the leaf positioned as desired, adjust the span locks to the specified clearances and such that the locks can be engaged without compromising the live load bearing contact or joint alignment.

There is one significant exception to the general design intent that locking mechanisms are not intended to align the movable span. In some cases center locks, span locks at the center joint of double-leaf bascule spans, are set to align and hold the alignment of the center joint. This is because the roadway and sidewalk surfaces either side of the joint may not be uniform under all conditions, either because of construction tolerances or due to thermal effects. Small deviations in the roadway surfaces are undesirable and can create a bump or drop in the roadway surface. More significantly, a vertical offset in the sidewalk surfaces may result in a violation of ADA criteria. Therefore, in some cases, short of adjusting the level of the deck or sidewalks, the center locks are called upon to pull the deck into alignment. When this is the case, optimize adjustments so that engaging the locks does not cause the live load bearings to loose contact. It is suggested to start by splitting the difference of any cross slope variations. For example, if the total cross slope difference in two adjacent spans is ½", set on side up ¼" and the other side down ¼". Then work from that starting point to best adjust the live load shoe contact.

Special for Rolling-lift Bascule Bridges with Jaw and Diaphragm Center Locks

For rolling-lift bascules with jaw and diaphragm center locks, the procedure for adjusting the support and stabilization is similar to the procedure for trunnions bascules with the following exceptions:

Unlike the typical span locks on trunnion bascules that are engaged after the leaves are lowered and aligned, jaw and diaphragm center locks are engaged by the motion of the leaves as they are lowered together. For this reason the center locks are adjusted before the live load bearings. However, to assure that the center lock adjustments are made in concert with alignment of all the deck joints, it is recommended to set the live load bearing of the leaf having the jaw portion of the center lock first. After setting the first set of live load bearings proceed in the following order:

1.   Adjust the center locks to align the center deck and sidewalk joints

2.   Adjust the live load bearings of the other leaf

3.   Adjust the tail locks or stops on both leaves

Special for Strauss Trunnion Bascules with Articulating Counterweight

The counterweight for this type of bridge is attached to the bascule leaf by way of a counterweight trunnion. The counterweight moves along an arc, but does not rotate as the leaf does. In this configuration, the relative positon of the counterweight center of gravity to the leaf is fixed. Adjustments to the counterweight, via addition or removal of ballast only changes the weight and does not affect the location of the CG with respect to the leaf.

Summary and Conclusions

Support and stabilization systems are important to the serviceability and functionality of double-leaf bascule bridges. These systems support the movable spans in operation and in service conditions under a variety of live loads, wind loading and temperature variations. Proper inspection, adjustment and maintenance of the primary supports, drive machinery, live load bearings, lock mechanisms, span balance and associated systems and components is essential for the bridge to perform as designed. Worn, damaged or improperly adjusted components of this system can result in serviceability issues, such as inconsistent seating, faulty or unreliable limit switch contact, abnormal operational noises and excessive vibrations under live load.

General knowledge of design intent of the support and stabilization systems and components is imperative to evaluating and adjusting the system for best performance. Such knowledge is also important to adapting general corrective action means and methods to specific bridges having unique configurations or components. In particular, understanding span balance as an element of the system is important, including the most common approaches to bascule leaf balancing. In addition, the relationships between span balance, starting friction and bridge seating are considerations to be applied in assessment and adjustment of the system.

A holistic approach is recommended for inspection and identification of support and stabilization system issues requiring corrective action. Each of the components should be evaluated for proper functionality at the component and system level.

Common corrective action measures can be applied to most double-leaf bascule bridges and adapted for application to other bridges, including single-leaf bascule bridges. Such measures should be implemented with consideration for the interaction of the systems and components. Most notable is the need to perform corrective action in a specific order, based upon the specific type of bridge and equipment. Following the recommended order produces conditions that meet design intent, simplifies adjustments, and avoids excessive iterations in the adjustment process.

Understanding the design intent and following recommendations for inspection, assessment and corrective action presented herein provides a basis for development and implementation of best management practices for support and stabilization systems for double-leaf bascule bridges.