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Unique Operating Mechanism for a Bascule Bridge

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Introduction

Objective

This paper presents a summary of the development of a unique and innovative mechanism for operating bascule bridges herein referred to as an Integral Trunnion with Push/Pull Hydraulic Cylinder Drive. The intent of this paper is to convey the general design concept and unique details, identify and discuss specific advantages of the design, and present the specifics of the design as applied to the Treasure Island Bascule Bridge Replacement project. Included in the discussion are particulars of the intended construction process that the design is based upon and specifics of some of the rational analytical approach developed to address unique elements.

Successful innovation in engineering design, more specifically movable bridge engineering, can only be evaluated through real world testing and application. To that end, this paper also includes a discussion of the construction phase of the project, including some lessons learned.

Background

Keep it simple. This basic principle, one which engineers often strive to achieve but rarely do to their full satisfaction, is the impetus behind the innovative design of the new Treasure Island Bascule Bridge's operating machinery. Over the past century and a half or so of modern movable bridge design and construction, many machinery configurations have been tried with varying degrees of success. The focus of this paper is on trunnion bascule bridges. Examining modern era bridges we find numerous types of trunnions, including the most common types, such as simple trunnions, fixed trunnions, and Hopkins trunnions, as well as more complicated designs such as those patented by Strauss, Brown, Page and Rall. Even more variety can be found in a survey of trunnion bascule bridge drive systems. As with trunnions these systems vary from simple gear drives with enclosed speed reducers and a pinion that drives a circular rack to complex systems of gears, bevel gears, operating struts and articulating racks. In the latter part of the last century movable bridge engineers began utilizing hydraulic systems in their designs, adopting technology used on other heavy industrial applications. These systems too came in a great variety of configurations including hydraulic motors, hydraulic cylinders that push a bridge open, and hydraulic cylinders that pull a bridge open. The hydraulic systems themselves are also of numerous designs including open-loop, closed-loop, with or without horsepower limiting, etc. So much for keeping it simple.

Having been involved in the design of new and rehabilitation projects that included many of the previously mentioned systems, this author has strived to find balance between incorporating the most successful design concepts and details, applying innovation, utilizing caution in exploring new designs, and keeping it simple. As many designers find out these goals are often juxtaposed. Keeping it simple, while easy to achieve in concept, can often be lost in the process of developing a design and set of details that meet all the client's requirements, codes, and geometric constraints. In developing the concept for the new Treasure Island Bascule Bridge, past systems were studied and evaluated to find common ground for a simplified system that would encompass the movable span support system and drive machinery. Each of the major components was then further reviewed to identify the key functions and simplify the details. In addition to simplifying the system, specific goals of the design process for this project included:

- Integrate the structure and drive system
- Integrate the trunnion and structure
- Simplify hydraulic components
- Simplify trunnion field alignment
- Improve maintainability

The result is a solution that incorporates many familiar features in a unique and efficient configuration hereafter referred to as an integral trunnion with push/pull hydraulic cylinder drive. The configuration consists of a tubular trunnion spanning between the bascule girders that serves as both a pivot mechanism for the bascule leaf, providing support and enabling rotation, and the structural fulcrum about which the drive system forces act to rotate the leaf. Working in concert with the integral trunnion are four hydraulic cylinders configured in push-pull tandem pairs. Each pair of cylinders is connected to the integral trunnion by way of a torque arm. The net result is a system that provides the functions of support, freedom of rotation, and leaf actuation all in one simplified mechanism. The basic configuration is shown in Figures 1 and 2.

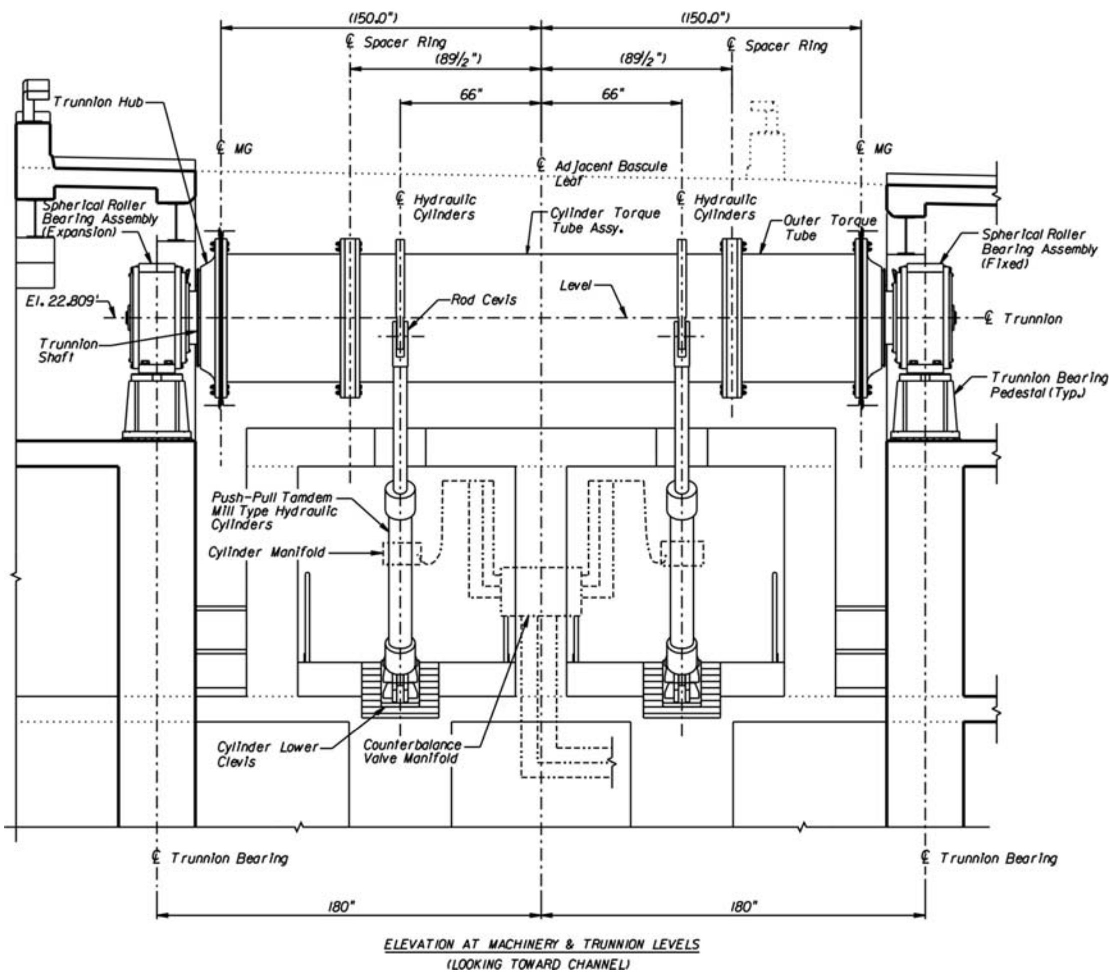


Figure 1 - Elevation of Integral Trunnion Assembly

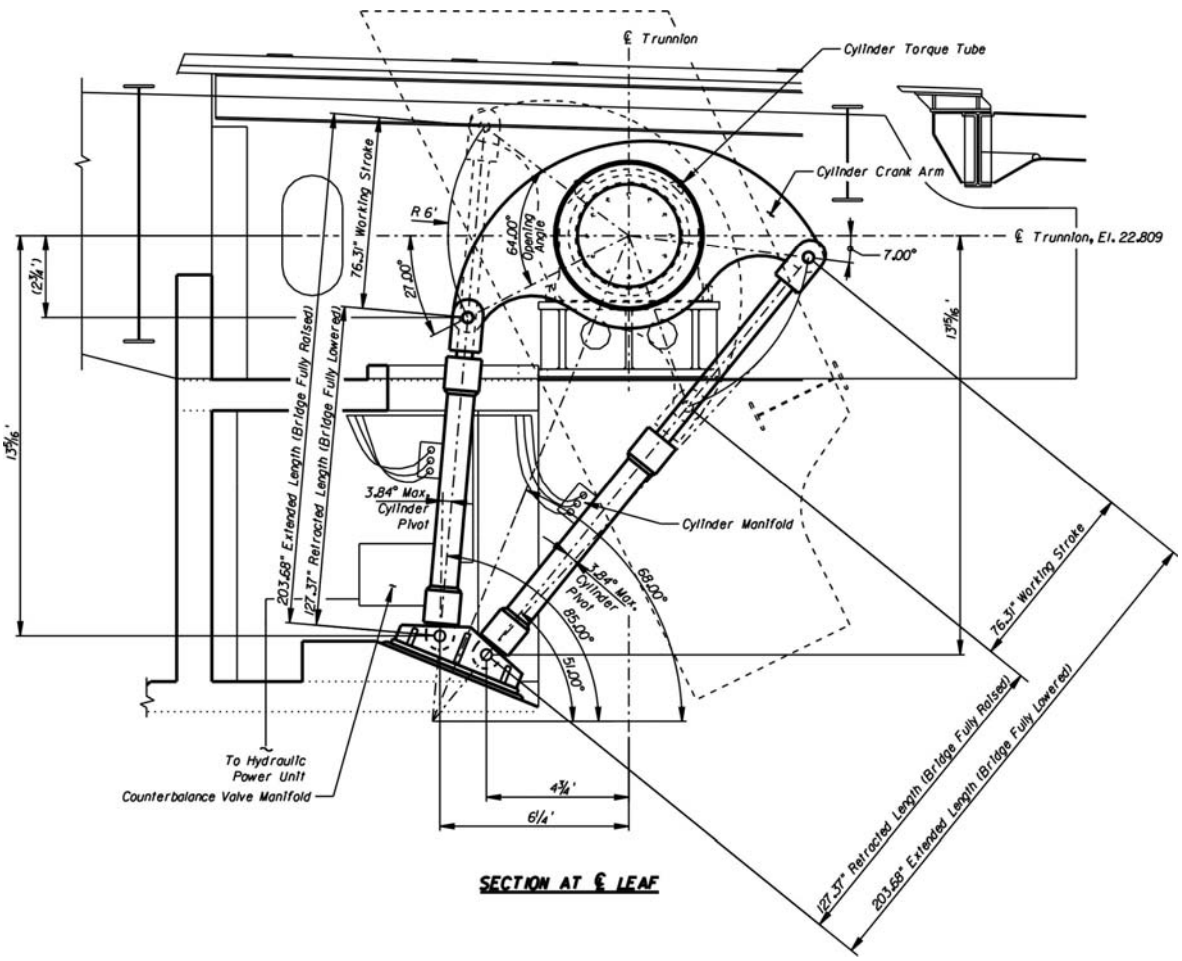


Figure 2 - Longitudinal Section at Push/Pull Hydraulic Cylinders

Project Description

The new Treasure Island Causeway Bridge is a 1,014-foot long structure spanning the Gulf Intracoastal Waterway (Boca Ciega Bay) in the City of Treasure Island, Pinellas County, Florida. The main channel span consists of twin double-leaf bascule spans with a length of 176 feet between trunnions. This main span provides clearance for a 100-foot wide navigation channel and 21 feet of vertical clearance with the bascule leaves in the lowered position. Each of the twin roadways features a 27-foot wide roadway and carries two lanes of traffic. The north half (westbound) of the bridge also features a 10-foot wide multiuse path. For enhanced durability and improved ride, the movable span is constructed with an exodermic deck, featuring a solid lightweight concrete riding surface.

Table 1 summarizes the key engineering details of the design that are related to the design and selection of the trunnion and drive system for the bascule span:

TABLE 1 TI Bascule Span Data		
Feature	**Eastbound Bridge**	**Westbound Bridge**
Leaf Weight (kips)	1,400	1,620
Leaf Length Trunnion to Tip (ft)	88.0	88.0
Leaf Width	30'-2"	41'-1"
Maximum Operating Wind Load (kip-ft)	1,070	1,417
Angle of Rotation (deg)	64.0	64.0
Time of Normal Operation (sec)	60	60

Rendering of New Treasure Island Bascule Bridge

Integral Trunnion Design

The primary reasons for integrating the trunnion with the bascule leaf structure are threefold. First, it provides a means to utilize details that facilitate assembly and simplify alignment of the structure and machinery. Second, it provides for improved distribution of operating loads to the structure. Third, it provides a means to simplify the overall structural and mechanical configuration, thereby improving economy.

From its initial inception the integral trunnion was designed to simplify assembly and erection. Erection and alignment of a typical trunnion bascule requires shop pre-alignment during fabrication and precision adjustment during field erection. In the case of simple trunnions, the four trunnion bearings of a bascule leaf must be set with precision on a common axis. For a Hopkins Trunnion the eccentrics must be adjusted to proper alignment, accounting for dead load deflections, such that the trunnions do not wobble excessively during leaf rotation. The field alignment work for each of these bridge types is exacting, especially considering that much of the work is inseparable from the steel erection work performed by iron workers. The integral trunnion simplifies the process greatly. With the integral trunnion design the bascule leaf is essentially constructed around the trunnion in the shop and is therefore inherently aligned with the trunnion. Similarly, in field erection, the leaf is erected around the trunnion assembly and can only be fit together in the aligned position. No field adjustments are needed except as required to position components so that they can be assembled with turned bolts.

The Integral Trunnion for the Treasure Island Bridge consists primarily of two Trunnion Shafts, two Trunnion Hubs, two Trunnion Collars, two Spacer Rings, and three sections of torque tube - two Outer Torque Tubes, 57.25 inches long and an Inner Torque Tube 174 inches long. The general arrangement of the components is shown in Figures 1 and 3. The torque tubes are 60 inch outside diameter tube with 1 inch thick wall formed from rolled ASTM A709 steel plate. The end of each section of tube is welded to a 2 inch thick flange plate. The Inner Torque Tube has two crank arms mounted to it that provide a connecting point and lever arm for the pairs of hydraulic cylinders. Spherical roller bearings support each end of the trunnion assembly and accommodate trunnion shaft slope that results from deflection of the trunnion shaft and torque tubes.

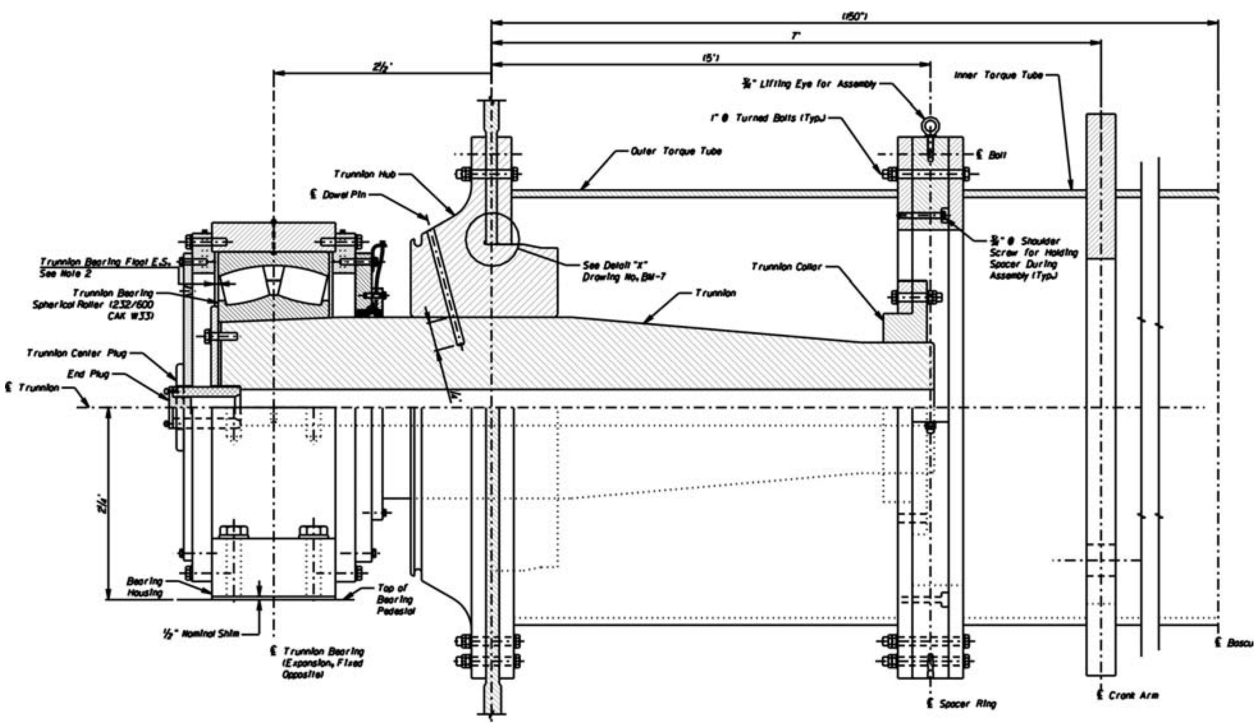


Figure 3 - Partial Section of Integral Trunnion Assembly

The following outlines the intended fabrication and erection process for the Treasure Island Bridge integral trunnion:

I. Shop Fabrication:

a) Fabricate the trunnion tube sections (Outer Torque Tubes and Inner Torque Tube) using precision machine tools such that the ends of all torque tube flange plates are normal to the axis of the assembly and the trunnion shaft is concentric with the axis of the assembly.

b) Bore the holes for the Crank Arm clevis pins, located in the torque arms of the Inner Torque Tube, parallel to the trunnion axis, offset by the proper distance and orientation relative to the trunnion axis.

c) Fabricate and machine the Trunnion Hub and Trunnion Collar such that the bores and flanges are normal to each other.

d) Measure the length of the torque tubes and finish machine the spacer rings to the thickness required to achieve the specified torque tube assembly length.

e) Prior to bascule leaf assembly, install the Trunnion Hub into each Bascule Girder.

f) Install the Outer Torque Tubes onto the Trunnion Hubs. Drill and install turned bolts.

g) Install the Trunnion Shafts into the Trunnion Hubs.

h) Install the Trunnion Collars. Drill and install turned bolts.

i) Set both Bascule Girders of a bascule leaf in the aligned position in the shop. Support the Outer Torque Tubes so they are approximately level and on a common axis.

j) Position the Inner Torque Tube between the Outer Torque Tubes and adjust its position and orientation to proper alignment.

k) Final machine and install the Spacer Rings. Drill holes for turned bolts.

l) Complete shop erection of bascule leaf structural steel.

II. Field Installation

a) After establishing the location of the centerline of the trunnion in the field, install the trunnion bearing pedestals in the proper location.

b) Place falsework on jacks between the trunnion bearing pedestals to temporarily support the Outer Trunnion Tubes and Inner Trunnion Tube approximately centered on the established trunnion centerline.

c) Place temporary blocking and jacks at the bascule leaf live load shoe.

d) Install the trunnion bearings onto each of the trunnion shafts, including the bearing housings.

e) Lift each bascule girder into position and support at three points, the trunnion bearing (on the trunnion pedestal), the live load shoe blocking, and the Inner Torque Tube falsework. Using jacks adjust each girder to its proper elevation and rotation.

f) Lift the Inner Torque Tube into position and support it on falsework. Using jacks adjust the location of the Inner Torque Tube such that it is aligned with the Outer Torque Tubes, rotated to the proper orientation of the clevis pin holes, and aligned with the holes in the Spacer Rings so that the turned bolts can be inserted.

g) Sequentially install the turned bolts connecting the Inner and Outer Torque Tubes.

Design

The Integral Trunnion presents the designer with several challenges. The Integral Trunnion is subject to loads due to dead load from supporting the bridge, vehicular live loads, and operating loads. It therefore must be analyzed as a machinery component and as structural component. Treasure Island Bridge bascule leaf structural steel was designed using the allowable stress design method of the AASHTO Standard Specifications for Highway Bridges, 1996 edition (AASHTO Standard Specifications). The machinery was designed using the AASHTO Standard Specifications for Movable Highway Bridge, 1988 edition (AASHTO Movable). When addressing different component classifications it is important to differentiate structural loadings and structural allowable stresses from operating loadings and appropriate machinery allowable stresses. The following rational approach was developed for design of the Integral Trunnion after careful consideration of all the design issues.

Strength Case: The strength load cases included dead load plus live load plus impact and dead load plus maximum wind loads. Live load is applied as trucks pass over the leaf in the closed position, loading the main girders and causing reactions in the Trunnion Bearings. The maximum wind load forces are resisted by forces in the push-pull hydraulic cylinders and are induced either when the rotating leaf is struck by sudden wind gusts or the stationary leaf is subjected to holding wind loads (AASHTO Movable 2.5.3.3, Condition C or E). These are considered "strength" conditions and are checked against maximum allowable stress. The strength condition was assumed occurring when the hydraulic cylinder pressure reached 1.5 times the cylinder pressure relief valve setting, in this case 1.5 x 3,150 psi = 4,725 psi.

As all components of the assembly are fabricated with ASTM A709, Grade 50 steel the allowable stress limit for the strength case was established as $0.55 \cdot F_y = 27.5$ ksi. Because of the unusual geometry as compared with conventional structural steel girders, this limit was applied to the larger of principal (both tensile and compressive) stress and von Mises stress. Since this value is usually applied to direct tension/compression or bending stresses, it is somewhat conservative, but appropriate for a unique application such as this. Critical buckling stress for both bending and torsion of the tube was determined to be higher than the allowable stresses for strength and therefore determined not to control the design.

Service (fatigue) Case: Service load cases included live load plus impact and combinations of dead load plus operating wind with the leaf in various positions of rotation. These conditions are recognized as "service loads" and are used in conjunction with fatigue analysis. Wind load is applied as forces from the push-pull hydraulic cylinders work against service wind loads (AASHTO Movable, 2.5.3.1, Condition A). In analysis, the forces were applied to the Integral Trunnion at the location of the clevises. For fatigue limit, forces for both bridge opening and closing were applied with the bascule leaf rotated to positions of 0, 16, 32, 48, and 64 degrees.

Fatigue is a complex issue, depending on many factors, such as frequency of the load occurrence, load uncertainty, geometry of the detail, etc. The AASHTO Standard Specifications have well-established stress range limits for specific fatigue categories for use in evaluating fatigue due to predicted truck traffic. However, stress ranges resulting from cylinder force loads cannot be used in conjunction with these limits as they are only calibrated for predicted truck traffic. No other part of the code deals with these stresses in an effective manner. Therefore the approach for fatigue analysis of machinery presented in Article 6.6.3 of the AASHTO LRFD Movable Highway Bridge Design Specifications, 2000 was used. This method provides a rational approach for evaluating fatigue in machinery parts where the load and number of load cycles are known.

For truck loading fatigue analysis the AASHTO Standard Specifications provides limits for live load stress range. The tube to flange welds at both the main girder and at the tube splice are designed as full penetration welds. Therefore, their fatigue classification is Category C with an allowable stress range of 10 ksi. Tube material at the torque arms is a base member with an attachment, i.e. its fatigue classification is Category D with a corresponding allowable stress range of 8 ksi. This is based on the Treasure Island Causeway's classification as a major arterial with Average Daily Truck Traffic (ADTT) less than 2,500 and a corresponding number of stress cycles of 2,000,000.

The estimated number of bridge openings is 7,200/year with a design life of 75 years. Considering four cycles per opening (accelerate and decelerate during raise and lower operations) yields (75*7,200*4 =) 2,160,000 cycles over the design life of the structure. To find the endurance limit of the steel, S_e, we use the following formula (AASHTO Movable 6.6.3.2):

$$S_e = \alpha \cdot S_{ult} \cdot \left(C_D \cdot C_S \cdot C_R \cdot C_T \cdot C_M\right)$$

where:

α = Factor of material; here: alloy steel $\alpha = 0.5$.
C_D = Size Factor; here $C_D = 1.0$ due to FEM computed stress.
$C_S = a \cdot (S_{ult})^b$ = Surface Roughness Factor; here: rough finish, therefore $a = 57.7$
$b = -0.718$, $S_{ult} = 450$ MPa (65 ksi). Therefore $C_S = 0.72$.
C_R – Reliability Factor; here: $C_R = 1.0$, minimum specified ultimate strength used.
C_T – Temperature Factor; here: $C_T = 1.0$, no extreme environment conditions.
C_M – Miscellaneous Factor; here $C_M = 0.95$, unique design.

resulting in:

$$S_e = 0.5 \cdot 65 \cdot (1.0 \cdot 0.72 \cdot 1.0 \cdot 1.0 \cdot 0.95) = 22.2\, ksi.$$

If the calculated stress range remains below this value, the fatigue condition is satisfied.

Analysis and Results

Stress analysis of the Integral Trunnion was performed using a three dimensional finite element model and GT Strudl software. The results are summarized below:

Strength Case Results

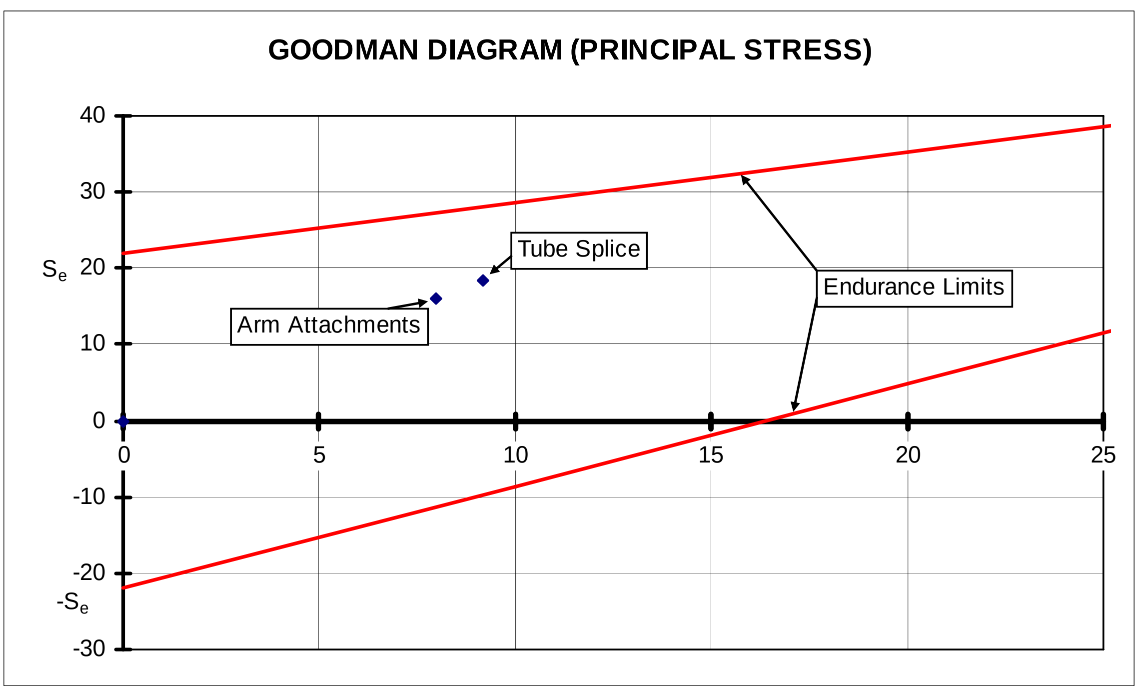
Tube: Both dead and live load resulted in stress in the longitudinal direction of the tube being predominant (i.e., the tube behaves closely to a simply supported beam with stress concentrations around the splice and torque arms.) The maximum normal stress due to dead load only was ± 17 ksi. Live load increased the stress magnitude by 4 ksi to ± 21 ksi. Maximum von Mises stresses were computed to be 18.4 ksi. The magnitude of stresses from loads resulting from applied cylinder forces was similar to that from live and dead loads: 20 ksi maximum tensile, 18 ksi maximum compressive, 18.2 ksi maximum von Mises stress.

Torque Arms: The magnitude of the stress levels at the torque arms was similar to that in the tube. Maximum tensile stress was 21 ksi at the bottom of the torque arms, maximum compressive stress was 14 ksi at top of the arms, and maximum von Mises stress was also 21 ksi.

Fatigue Case Results

Fatigue Stress Range in Tube from Live Load: The maximum stress range in the tube occurred at the splice and had a magnitude of 9 ksi, (i.e. less than the stress limit of 10 ksi for fatigue detail Category C.) Other fatigue detail regions also displayed stress ranges within the allowable limits: maximum stress range at the main girder was 5.7 ksi (< 10 ksi limit), and at the torque arm attachments 6.6 ksi (< 8 ksi allowable).

Fatigue Stress Range in Tube and Torque Arms from Cylinder Forces: Results from 10 loading conditions were combined in such a way that each stress state was subtracted from each other (e.g. results from opening at 0 degrees from results at closing at 32 degrees and vice versa). This created 81 stress states, each of them having a principal stress value and envelope which allowed determination of a maximum principal stress range at each node of the tube and torque arms. The maximum magnitude of the principal stress range for the tube was found to be 18.4 ksi at the tube splice and 16 ksi at the torque arm attachments. This magnitude is close to the maximum stress found due to dead load (17 ksi) and is caused by the changing position of the maximum top fiber bending stress (note that the tube rotates, but the dead load direction remains the same, exposing new fibers to the same stress). The Goodman diagram presented below shows that the stress in the tube remains within the endurance limits of the material.



The envelope of those 81 stress states in the torque arms exhibited a maximum stress range of just 3.6 ksi, which leads to the conclusion that fatigue is not a concern for the torque arms.

Hydraulic System

Hydraulic Power Unit Shop Test

Design of a hydraulic cylinder drive system for a bascule bridge involves study and optimization of cylinder positioning; cylinder bore diameter, and cylinder rod diameter. The focus of optimization is to balance the design so that one controlling parameter does not skew the design away from efficiency. For example, consider a design in which the cylinders push the bridge open (note that a bridge in which the cylinders pull the bridge open faces similar issues.) If the cylinders are positioned such that there is a large effective moment arm of the cylinder force vector acting about the axis of rotation, this will reduce the required bore of the cylinder needed to open the bridge. However, the price for a large moment arm is a long cylinder stroke and the resulting need to increase the rod diameter to provide adequate buckling resistance. As the rod size is increased to solve the buckling criteria requirement, the area of the cylinder available to pull the bridge closed is reduced and the cylinder bore needs to be increased to compensate. If the same bridge is designed with the cylinders positioned such that there is a short effective moment arm, buckling can be eliminated as a controlling element of the design. However, the cylinder forces will increase dramatically, even to the point that structural design of the connections becomes unwieldy and/or the cylinder forces become a significant load on the trunnions and trunnion bearings. As can be seen from the above example optimizing such a system becomes a matter of determining the best compromise.

A second significant issue encountered in design of bridges that have hydraulic cylinders that either push the bridge open or pull the bridge open is that the hydraulic flows differ significantly for opening or closing the bridge. For a typical cylinder with a ratio of blind end area to rod end area of 2:1, the flow in one direction is twice that of the flow in other direction. This creates problems in optimizing the sizing of valves and either leads to the use of different size valves or compromise on sizing.

The push/pull arrangement of the hydraulic cylinders used in the Treasure Island Bridge design effectively eliminates buckling as a controlling element of design and results in equal flows for raising and lowering the bridge, thereby allowing for optimization of hydraulic components. In effect, the push/pull tandem pairs of cylinders act like equal area cylinders. A conceptual design level comparison between a push cylinder arrangement and a push/pull arrangement clearly demonstrates the advantages of the push/pull cylinder configuration. A summary of the comparison is presented in **Table 2** below.

TABLE 2 Comparison of Cylinder Arrangements TI Bascule North Bridge		
Design Element	**Push/Pull Cylinders**	**Push Cylinders**
Number of Cylinders	4	4
Cylinder Bore Diameter	8.66 in	9.84 in
Cylinder Rod Diameter	6.30 in	6.30 in
Working Stoke	76.31 in	76.31 in
Maximum Pressure Holding	3,100 psi (raise)	2,900 psi (lower)
Average Operating Press. Raise	536 psi	306 psi
Average Operating Press. Lower	261 psi	252 psi
Max. Operating Press. Raise	1,607 psi	915 psi
Max. Operating Press. Lower	1,574 psi	1,518 psi
Pump Flow Raise	68 gpm	120 gpm
Pump Flow Lower	68 gpm	70 gpm
Minimum Horsepower/Leaf	40 (36 calculated)	60 (53 calculated)
Net Reservoir Fluid Exchange	0 gallons	41 gallons

From **Table 2** it can be seen that the push/pull configuration results in generally higher operating pressures and lower operating flows than the push configuration. For hydraulic systems it is commonly said that pressure is cheap and flow is expensive. The reason for this is that system inefficiencies are mostly attributable to flow. Similarly, component sizing is significantly affected by flow but only rarely affected by pressure, particularly in the pressure ranges used in bridge drives. In other words, a system that performs work at a higher pressure will be more economical than one that performs the same work at a lower pressure. This is clearly evidenced by the difference in required horsepower, 36 versus 53, of the two systems compared above.

Other advantages of the push/pull system realized in the hydraulic system design, detailing and maintenance include:

- Piping sizes are reduced due to use of lower flows,
- The fluid level in the reservoir remains essentially constant, thus eliminating the need for large, maintenance intensive desiccant breathers to filter water vapor out of the exchange air,
- Valves handling the raising and lowering flow can be identical, thereby reducing the types and sizes of components and making spare parts interchangeable.

The advantages listed above not only reduce initial construction cost, but more importantly reduce maintenance costs and improve reliability.

From a structural standpoint there are also advantages to the push/pull cylinder arrangement. Unlike a push or pull configuration the torque applied to rotate the bascule leaf is the result of two force vectors. The net affect is to reduce the net force applied to the leaf. The cylinder forces result in less net force on the trunnions while providing the same net torque. For the Treasure Island Bridge this advantage was also made use of at the connection of the cylinders to the bascule pier. By co-locating the cylinders of a push/pull pair on the same clevis base the net force of the clevis base on the pier is greatly reduced. In fact, since the larger force of the cylinder pair will always be in the push direction, the net forces on the clevis base always result in compression against the concrete of the bascule pier. To provide for a high degree of safety and redundancy the anchorage of the clevis base to the pier was designed for the full force of one cylinder acting to pull the base from the concrete.

Construction

At the time of this writing the north half of the Treasure Island Bridge was substantially completed and opened to traffic for several months. For the most part construction of the Integral Trunnion and hydraulic system went as anticipated and there were few problems.

Field Erection - Main Girders & Inner Torque Tubes

Maintaining the geometry of the flanges on the torque tubes throughout fabrication was difficult. The end flange plates tended to distort like large beveled washers during the welding process. In some cases the flanges needed to be machined to less than the specified thickness in order to achieve a flat surface normal to the tube axis. A review of the analysis indicated that the reduced sections were acceptable and the parts were accepted as fabricated. For future designs a greater allowance for machining and possibly some internal stiffeners and modified welding details would likely eliminate this problem.

Field Erection - Placing Inner Torque Tube

The fabricator had some difficulty maintaining hole tolerances when drilling and reaming the holes for the turned bolts that connect the Inner and Outer Torque Tubes. Including the spacer rings this operation involves drilling and reaming though a stack of three plates with a total thickness of 9 inches. In some cases the holes had to be reamed oversized and larger turned bolts installed to get the proper fit throughout the depth of the hole. To reduce the potential for this problem the spacer ring and one mating torque tube can be preassembled and drilled, leaving only one 2 inch plate to be drilled at assembly.

Integral Trunnion and Push/Pull Hydraulic Cylinders from Inside Bascule Pier

The contract documents included cushion at both ends of the hydraulic cylinders. Also included was a requirement for the cylinder manufacturer to provide detailed calculations and details for the cushions. The cylinder manufacturer came up with the idea of providing cushions only at the blind ends of the cylinders. This idea was reviewed in detail and adopted. The advantages to consolidating the cushioning into one end of the cylinders are twofold. First, the blind end cushion area is much greater than the rod end and therefore significantly more effective. Second, one larger and more effective cushion requires less cylinder length than two smaller cushions. Because there are always two blind end cushions effective at each end of cylinder travel (2 of the four cylinders) this method is effective for the push/pull cylinder configuration. Adopting this approach allowed the blind end cushions to be increased in length, resulting in smoother and more controlled cushioning.

Conclusions

The Integral Trunnion, as designed and constructed for the Treasure Island Bridge, is a simplified trunnion system that combines the movable span support system and drive machinery interface in a cost effective and functional manner. The configuration of the equipment integrates the structural functions of bascule span support with the mechanical functions of allowing for and actuating rotation. Alignment of the trunnion on its axis and with the bascule structure is simplified as the Integral Trunnion functions as the focus of shop and field erection, allowing precision machined components to dictate the alignment.

This confines the most difficult alignment issues to the shop and simplifies the efforts in the field where precision is more difficult to achieve.

Push Cylinder Rod Clevis at Torque Arm

Bird's Eye View of Integral Trunnion Assembly

The push/pull hydraulic cylinder system equalizes the flows for raising and lowering the bridge, thereby simplifying the design, detailing, and maintenance of the drive system. With components on both sides of the cylinder subjected to similar flows and pressures the design allows for optimization of the hydraulic circuit and reduction in the number of different sized valves required. This reduces cost and improves maintainability and reliability.

The Integral Trunnion with Push/Pull Hydraulic Cylinder Drive has proven itself to be a viable bascule bridge support and drive system that should be considered for further development and use. The development of the Treasure Island Bridge design has paved the way and demonstrated that unique aspects of the design can be satisfactorily analyzed and evaluated using current accepted codes and standard practice. Furthermore, the project has proven through construction and into operation that the desired advantages of the Integral Trunnion with Push/Pull Hydraulic Cylinder Drive are readily achievable.