Heavy Movable Structures, Inc.

SEVENTH BIENNIAL SYMPOSIUM

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Walt Disney World Village
Lake Buena Vista, Florida

"Single Leaf - Integral Trunnion Bridge"

by

James M. Phillips, III, P.E., E.C. Driver and Associates, Inc.

“Single Leaf - Integral Trunnion Bascule”

Universal Studios Islands of Adventure™, Orlando, FL

HEAVY MOVABLE STRUCTURES, Inc.
7th BIENNIAL SYMPOSIUM

By James M. Phillips, III, P.E.
E.C. Driver and Associates, Inc.
500 North Westshore Blvd, Suite 700
Tampa, Florida 33609
Phone (813) 282-9886
Fax (813) 282-9873

"Single Leaf - Integral Trunnion Bascule", Universal Studios Islands of Adventure™, Orlando, FL

INTRODUCTION

How do I get from Seuss Landing to the Lost Continent?

For many a layperson the answer to this question will be to *cross the old wooden drawbridge over the moat.* For others, whose eye for bridges is more keen, the answer will be to cross the moat by way of the bascule bridge. This is as it has been since the storied times of castles and battering rams. Since medieval times the drawbridge has provided controlled access to a desired location across a moat. It is therefore fitting that at the Universal Studios Islands of Adventure™ (USIOA™) theme park a drawbridge will provide the entrance to the section of park known as the Lost Continent. Naturally, in the spirit of theme park creativity, the selection of a drawbridge and the fact that it will look like an old wooden drawbridge are by design. The fact that the bridge incorporates many unique and interesting features is also by design.

Universal Studios Islands of Adventure™ is a theme park centered around a man-made lagoon. The park features several islands, each portraying a unique theme. Access from a marina to the main lagoon for show boats and other park vessels is provided by way of a navigable channel, which is presented as a moat between the islands of Seuss Landing and the Lost Continent. The park's designers established basic criteria for a bridge across the moat, including the geometric criteria and a theme. The waterway was required to provide a 20 foot wide channel. The bridge itself was required to provide safe passage for either pedestrians or vehicles by way of a 20 foot wide carriageway. To provide unlimited vertical clearance for vessels, a drawbridge was specified. Park designers envisioned that the bridge would be an integral part of the park theming through implementation of a style visually consistent with the "Lost Continent" theme.

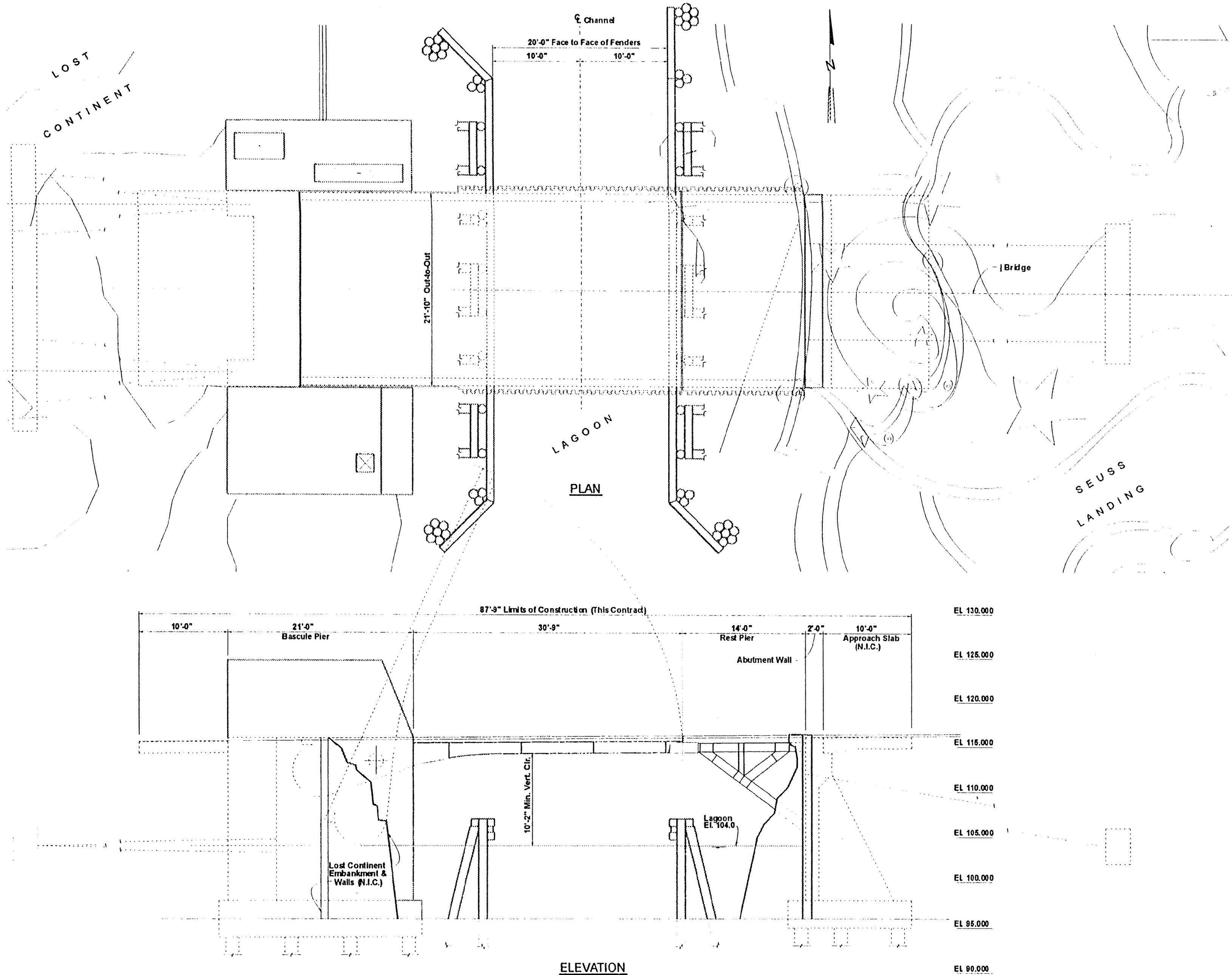
DESIGN/BUILD CONTRACT

This project was initially contracted to Johnson Brothers Construction Corporation of Litchfield, Minnesota, as a part of the site work at the new park. Due to budget constraints and a desire to further integrate the bridge into the park's theme, a redesign was initiated by the owner utilizing a design/build concept. E.C. Driver and Associates, Inc., was contracted to perform design studies and final design.

Design Criteria

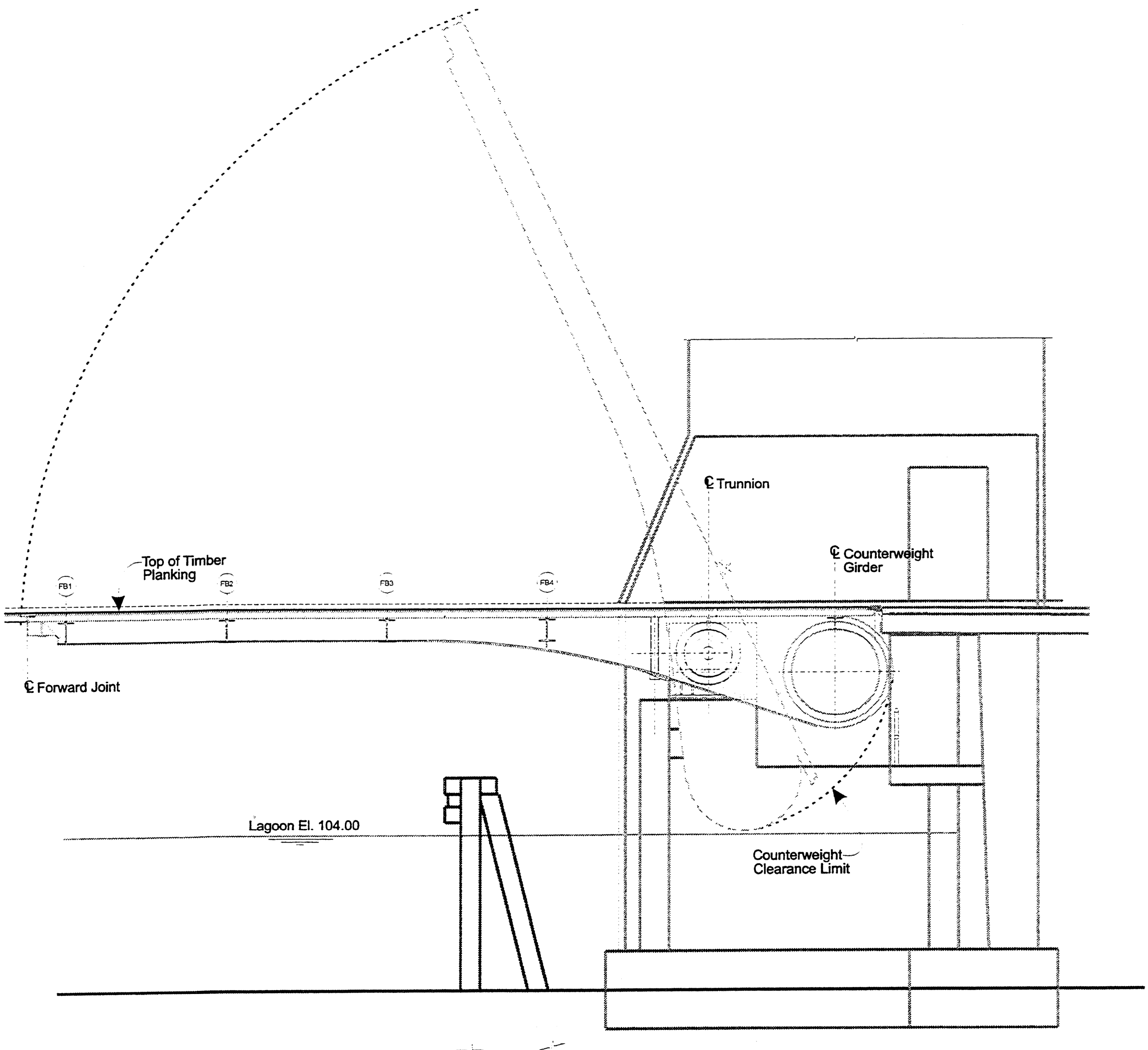
The goals and objectives for the bridge were established in a coordinated effort between the owners, the contractor, and the designer to meet the unique requirements of the facility. The basic design criteria was established as follows:

- Provide a movable span with 20 feet of horizontal clearance and unlimited vertical clearance (with the span raised)
- Design Code: AASHTO Standard Specifications for Movable Highway Bridges (AASHTO Movable) except as noted
- Live Loads: Single HS-20-44 truck loading at normal allowable stresses; Dual HS20-44 trucks as an "overload" condition; Truck traffic cycles less than 100,000
- Deflection criteria of the AASHTO Movable waived (in fact the designers wanted the bridge to be flexible to enhance the "wooden bridge" feel)
- AASHTO ice loading waived
- A 5-10 psf allowance on the bridge deck area to account for theming applied by the owner
- An 80 second normal operating time (raising or lowering)
- Interlocking hard-wired controls, no programmable logic controller or other automated operating features
- A drive system featuring redundancy of the major components, including hydraulic cylinders, pumps, and pump motors



LOST CONTINENT
SEUSS LANDING
LAGOON
℄ Channel
20'-0" Face to Face of Fenders
10'-0"
10'-0"
N
21'-10" Out-to-Out
Bridge
PLAN
87'-9" Limits of Construction (This Contract)
10'-0"
21'-0" Bascule Pier
30'-9"
14'-0" Rest Pier
2'-0"
10'-0" Approach Slab (N.I.C.)
Abutment Wall
10'-2" Min. Vert. Clr.
Lagoon El. 104.0
Lost Continent Embankment & Walls (N.I.C.)
EL 130.000
EL 125.000
EL 120.000
EL 115.000
EL 110.000
EL 105.000
EL 100.000
EL 95.000
EL 90.000
ELEVATION

FIGURE 1



LONGITUDINAL SECTION THRU BASCULE LEAF

FIGURE 2

Design Challenges

Several significant challenges were presented for the design/build team. Most challenging were the budget, schedule, and theming provisions.

The objective of the design/build assignment was to reduce this cost while meeting the design objectives and the original schedule. To achieve significant reductions in the estimated construction costs, without sacrificing function, performance, or aesthetics, required examining the configuration of the facility rather than simply scrutinizing specific details of the original design.

To maintain the original construction schedule required a fast-track design approach. This requirement was amplified by the fact that the bridge needed to be completed early within the site work schedule to allow for construction of subsequent elements of the work.

The park designers established both specific and general objectives for theming to integrate the bridge into the aesthetic concept for the Lost Continent section of the park. In general terms, the finished bridge was to look like an old drawbridge at a castle moat and be reminiscent of construction typical in medieval times. This was to be accomplished by a combination of selecting appropriate materials and applying decorative facades. Specific details, such as wood decking, were defined in the design criteria. To account for the general theming, decorative facades, and bridge railings, a 5 to 10 pound per square foot of deck area was specified.

Use of wood decking on the bridge was the most specific and challenging aesthetic requirement of the project. Wood decking was required to provide a surface one would expect to find on a medieval bridge. The challenge was to select timber which would be durable enough to endure heavy pedestrian traffic and light vehicular traffic and strong enough to support truck loads. Furthermore, the owner specified that the material could not be from a rain forest source.

KEY DESIGN FEATURES

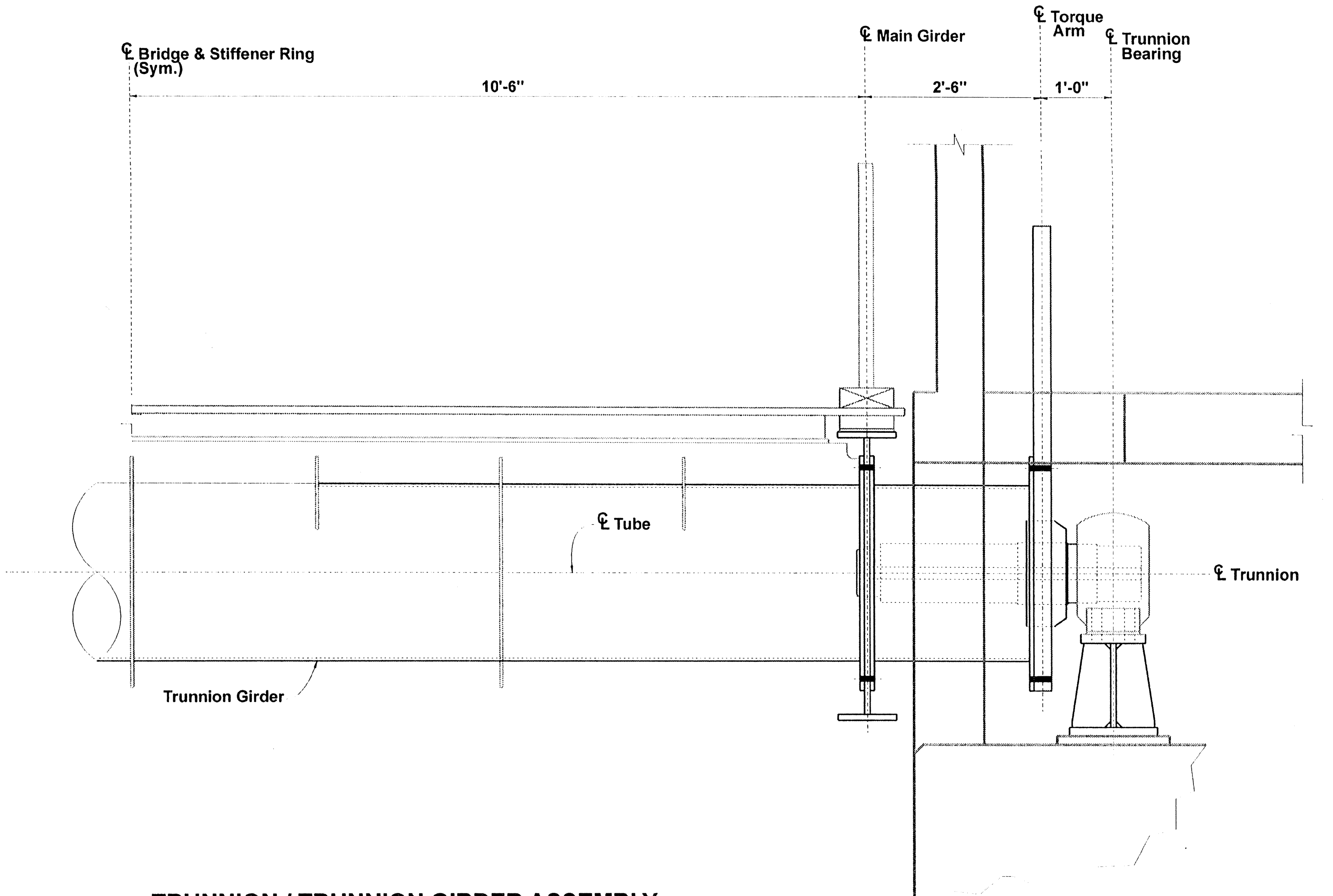
Although the bridge has many features which distinguish it from a more typical highway trunnion bascule, the single most unique features are the **Integral Trunnion and the Partially-Unbalanced Bascule design**.

Integral Trunnion

The integral trunnion design originated from a series of studies prepared over several years. The goal of these studies was to design a bascule bridge pivot mechanism which would provide for simplicity in design, function, and construction and whereby alignment of the device would be second nature to the fabrication rather than a complex process with many potential pitfalls. In the end, the concept of constructing the bridge around the trunnion, as opposed to inserting and aligning the trunnion within the fabricated bridge, provided the key. The result is the integral trunnion presented herein.

Many engineers before have worked toward the goals sought in this design. There are two specific bridge projects which provided inspiration for this design. One project, Sverdrup Civil's First Avenue South Bridge in Seattle, constructed in 1996, features a similar trunnion device consisting of a 10 foot diameter tube supported on segmented bronze bearings and driven by a pair of tandem cylinders. The second project, Modjeski and Master's Million Dollar Bridge in Portland Maine, constructed in 1996, features a cantilevered (Hopkins type) trunnion, for which the interior trunnion support is a diaphragm supported within a truss box girder which spans between the main bascule girders. Though not derived directly from either of these designs, the integral trunnion has features similar to both of these innovative designs.

Design Features: The integral trunnion is both the focal structural and mechanical element of the bascule structure. Furthermore, it is the nucleus of the erection and alignment process. The integral trunnion is a tubular element which spans between two trunnion bearings which, in turn, support the entire weight of the movable span as well as operating and live loads. The assembly is



TRUNNION / TRUNNION GIRDER ASSEMBLY

FIGURE 3

modular and consists of the following elements:

trunnion girder: section which spans between the main girders and supports the bridge deck (30" dia x ½" wall, ASTM A500, Grade B tube, ASTM A709, Grade 50 Structural Steel end plates and stiffeners)

trunnion girder extension: sections which connect to the trunnion girder at the main girder and to the torque arm (30" dia x ½" wall, ASTM A500, Grade B tube, ASTM A709, Grade 50 Structural Steel end plates and stiffeners, ASTM A36 Structural Steel Hub); also houses the trunnion

trunnion: shaft which is supported on the inboard end at the trunnion girder, at the trunnion girder extension near the torque arm, and cantilevers to the trunnion bearing (ASTM A668, Class G FCS)

torque arm: connected to the trunnion girder extension just inboard of the trunnion bearing (ASTM A572, Grade 50 Structural Steel)

trunnion bearing: two Self-aligning Spherical Roller Bearings, one each end of the assembly (Torrington SAF 23056K Pillow Block and Bearing).

In addition to achieving the primary goals sought in the integral trunnion, secondary but no less significant advantages were realized through use of this design. Having an arrangement in which the bearings and hydraulic cylinders are located outboard of the main bascule girders provides opportunities for increased span efficiency. With no inboard supports or mechanisms between the main girders, the angle of rotation of the span is not limited by conflicts between these elements and the underdeck counterweight. The result is a span which can open as far as 90 degrees if the situation dictates.

Counterweight-Assisted Bascule Design

Traditionally, bascule bridges are of a "balanced" design whereby the center of gravity of the movable span is essentially coincidental to the trunnion or axis of rotation, except for a relatively small imbalance applied by design to assist the bridge in seating. Some bridges have also been constructed as "unbalanced" designs without a counterweight. A third and less frequent design is the "partially unbalanced" design. A partially unbalanced bascule is one in which the movable span forward of the axis of rotation is partially balanced by the counterweight. The resulting unbalanced load of the span must be carried by the drive mechanism. When the magnitude of the unbalance is determined by design such that the total bridge efficiency, both structural and mechanical, is optimized, the bridge is more than just partially unbalanced. In reality, operation and control of the movable span (by the bridge machinery) is assisted by a specifically sized counterweight. Therefore the name this writer has stipulated for the design is a **"counterweight-assisted"** bascule.

To the best of this writer's knowledge, the USIOA™ Drawbridge is only the second counterweight-assisted bascule bridge, the other being the Lansing Island Bridge in Brevard County, Florida, constructed in 1989.

The conceptual study for the USIOA™ Drawbridge included a total facility cost study of balanced, unbalanced, and counterweight-assisted designs. The results indicated that the most economical structure would be a counterweight-assisted bascule, both in initial and life-cycle costs. The comparative initial construction cost estimates for the entire bridge, including conceptual level estimated quantities for structural, mechanical, and electrical systems, are as follows:

Design Configuration	**Relative Cost**
counterweight-assisted design	1.00
unbalanced design	1.03
balanced design	1.43

The hydraulic system requirements for the various designs were estimated as a method of comparing long term operational and maintenance costs. These requirements are summarized as follows:

Configuration	Pump Motors	Cylinders
Unbalanced Design	2@25 HP	2@12" Bore
Cwt-assisted Design	2@15 HP[1]	2@10" Bore
Balanced Design	2@10 HP	2@10" Bore

The result of this study was a recommendation to proceed with the design utilizing a counterweight-assisted design which was accepted by the owner and general contractor.

OTHER UNIQUE DESIGN FEATURES

Structural Framing: The structural system for the bascule leaf is both simple and efficient. Like most bascule bridges, this one features a two main girder system with transverse floorbeams. The main girders are spaced 21 feet apart to support the overall deck width of 21'-10". Unlike most bascule spans the deck system spans longitudinally between floorbeams. There are no stringers. The single leaf spans 35 feet from trunnion to tip where the main girders rest on load shoes supported on a cantilevered abutment. Between the tip and the trunnion are four floorbeams spaced at 8'-3" on center. The only transverse element back of the trunnion is the counterweight. Lateral bracing, in the form of rods and turnbuckles, is provided in the four bays between the trunnion and the end floorbeam.

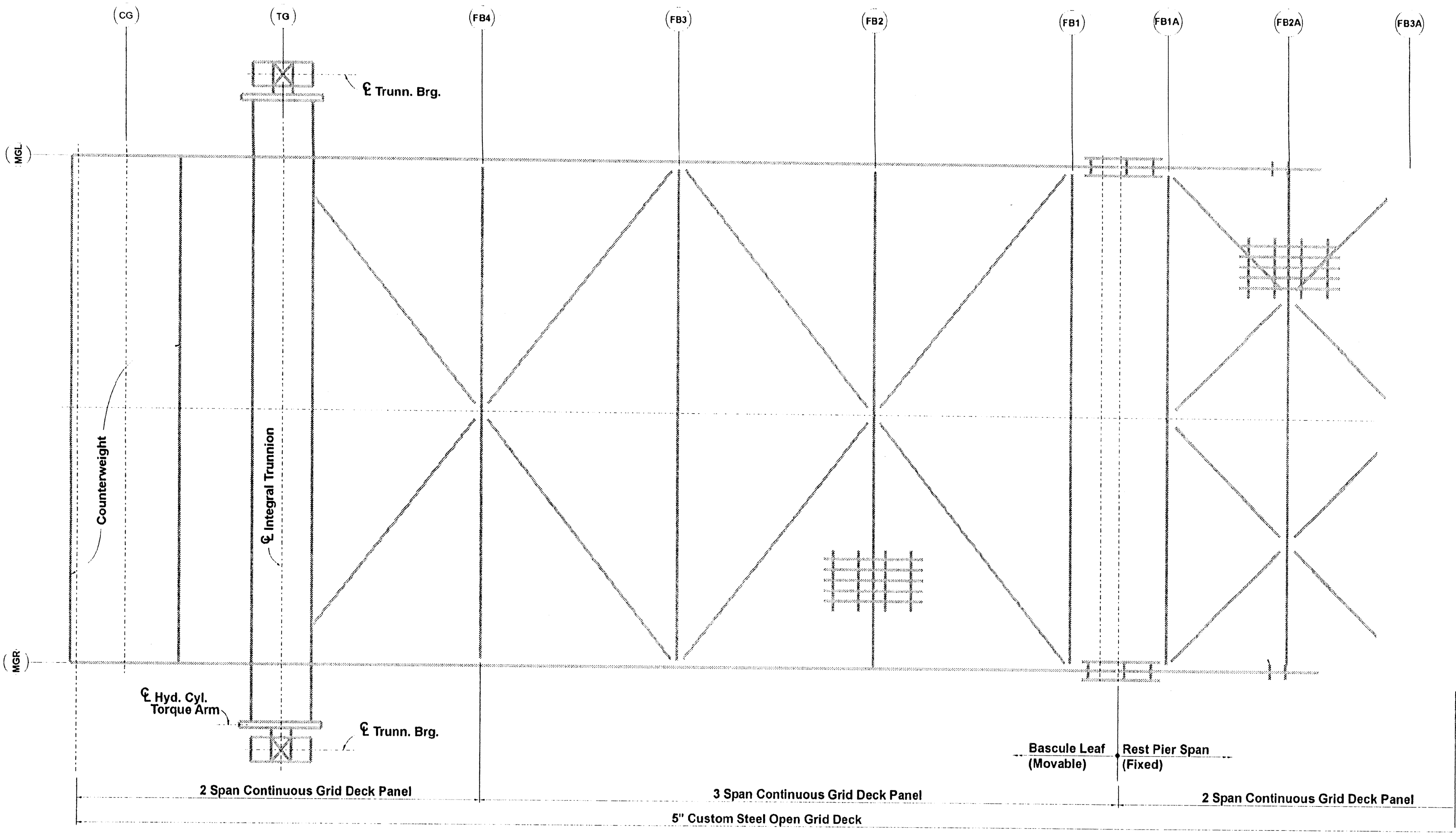
Counterweight: The counterweight element is unique and simple. It consists of a 54" diameter x ½" wall steel tube which spans between the main girders, centered 6'-6" behind the trunnion. The tube is filled with normal weight (146 pcf), unreinforced concrete for ballast. No balance block pits or other means of adjustment are required because the **counterweight-assisted** design includes provision in the drive system to accommodate a variation in unbalance greater than the adjustment range required by AASHTO for balanced bascule spans. This added benefit of the counterweight-assisted design greatly simplifies the counterweight design and detailing.

Deck System: To meet the project requirements for strength, durability, and aesthetics, a unique deck system was designed specifically for this project. The system consists of a combination of a steel grid deck and Jarrah timber decking. The steel grid deck is designed to carry the entire load of the deck and live loading between the transverse floorbeams. The deck is custom designed and includes S4x7.7 main bars at 6" on center and ¼"x 1½" cross bars. ASTM A572 structural steel is specified for all grid deck steel. Trim bars, shop welded to the deck bottom, are provided to facilitate bolting of the deck to the floorbeams. This detail eliminated field welding and provided for a simpler means for future deck replacement if necessary. The deck surface consists of 1¼" x 5" Jarrah, hardwood planking attached to the steel grid deck with hammered head bolts and self-locking nuts. The hammered heads were specified as an aesthetic finish to simulate construction materials of past centuries.

Redundant Hydraulic Cylinders: The bridge is actuated by a pair of 9.84" diameter bore, 5.51" diameter rod, by 59" stroke, heavy duty, mill type hydraulic cylinders. Each cylinder is mounted to the machinery platform of the bascule pier and connected to the integral trunnion by way of a torque arm. Plain spherical bearings in blind and rod clevises provide relief from side loading due to dynamic or static misalignment. The cylinder location and position were selected to optimize the bridge operation while eliminating the need to construct a pit below lagoon level to house the cylinder or its supports.

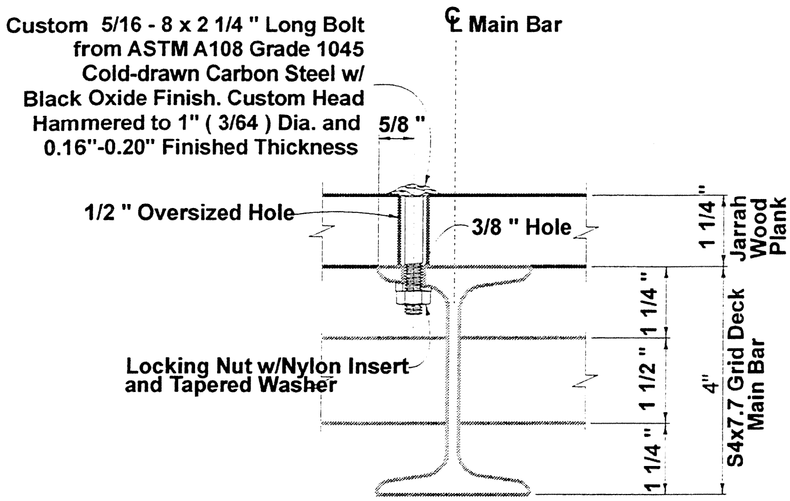
Hydraulic Power Unit: To meet the requirements for reliability and serviceability, the bridge drive is powered by a dual pump hydraulic power unit. This unit features a basic open loop circuit powered by dual 10 horsepower electric motors which drive variable displacement pumps (up to 2.44 cubic inches). The pumps feature

[1]Reduced to 10 HP in final design

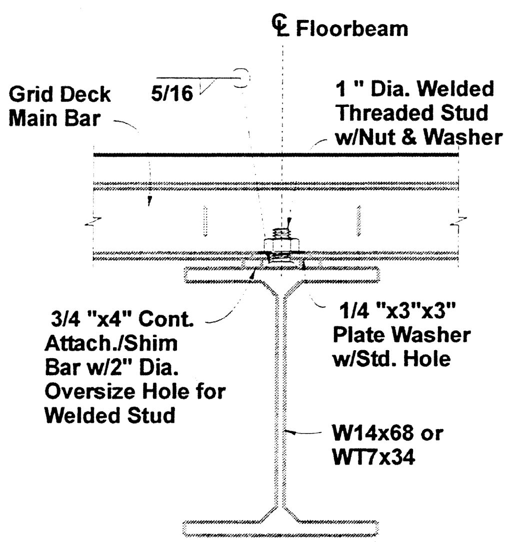


BASCULE LEAF FRAMING PLAN

FIGURE 4

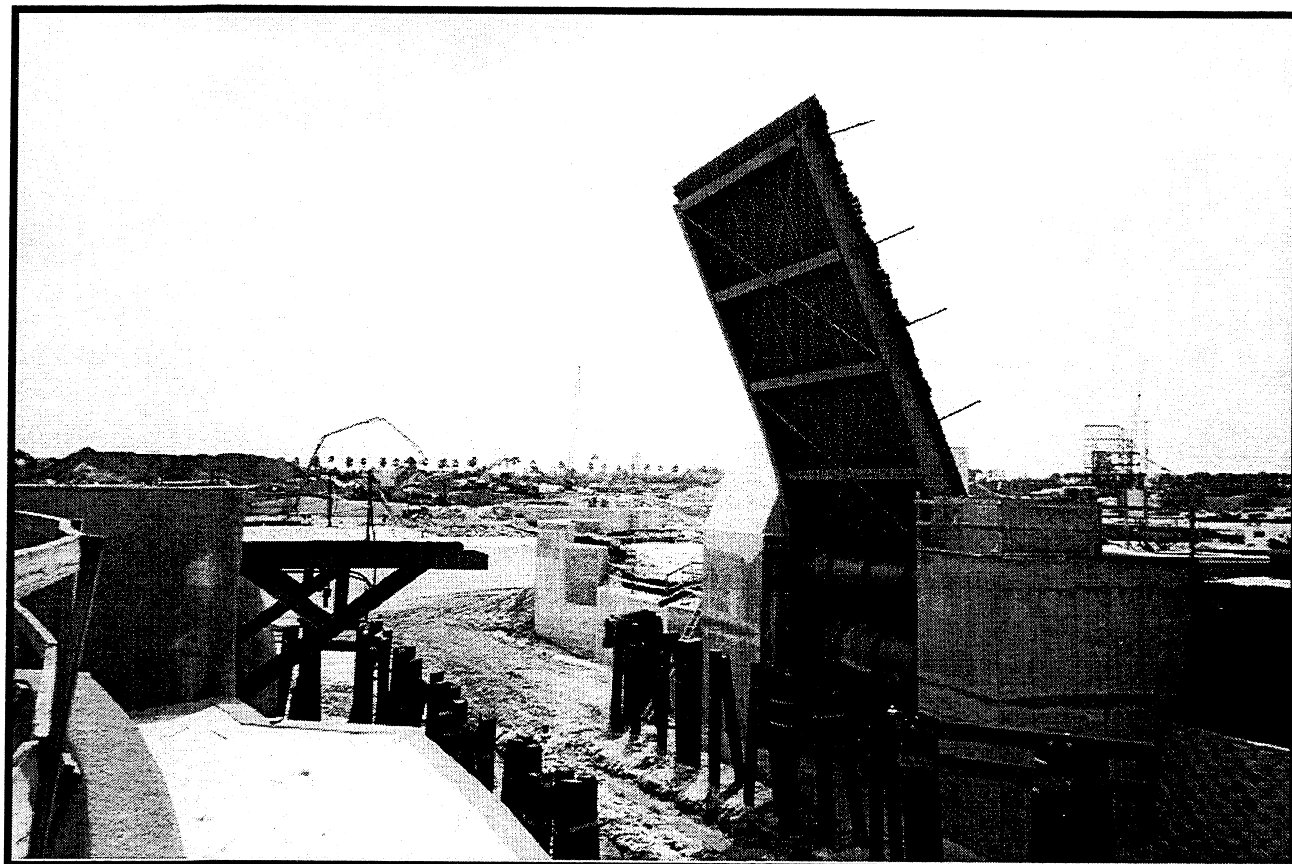


TIMBER PLANKING ATTACHMENT DETAIL



GRID DECK ATTACHMENT DETAIL

FIGURE 5



SINGLE LEAF-INTEGRAL
TRUNNION BASCULE
UNDER CONSTRUCTION

horsepower limiting control and pressure compensation. The power provides for the maximum required flow of 16 gpm per pump, the maximum cylinder working pressure under normal (AASHTO Condition A) loads of 1020 psi, and the maximum cylinder pressure under single cylinder or maximum winds of 2150 psi.

DESIGN ANALYSIS OF THE INTEGRAL TRUNNION

The integral trunnion is designed to support the appropriate combinations of dead load of the span, live loads on the span, and operating loads. Under normal operating conditions, the loads due to wind, unbalance, and inertia are distributed to each of the main girders and transferred from the girders to the trunnion as applied moments and shears. These loads produce shear, bending, and torsion in the integral trunnion. Subsequently, the torsion in the integral trunnion is resisted by the cylinder force applied through the torque arms. For the Integral Trunnion to be most effective and for the drive configuration to be fully redundant, the integral trunnion was designed to transfer the entire torque required to drive or hold the leaf to a single torque arm and hydraulic cylinder when the other cylinder is out of service.

AASHTO does not specifically address the design of tube sections subjected to combined bending and torsion. Therefore, a fundamental working stress method was adopted for design of the tube section. This approach involved computing moments, shears, and torsions at various sections of the tube under AASHTO load combinations, calculating the principle stresses under these conditions, and limiting the principle shear stress to $0.33F_y$ and the principle tensile stress to $0.55F_y$. The provisions of the AASHTO Movable code were used for design of the remaining elements of the integral trunnion.

SUMMARY

Drawbridges are often associated with medieval themes and adventures. To incorporate a drawbridge into the theme of the Universal Studios Islands of Adventure™ park, several unique and innovative design techniques were applied to the age old bascule type drawbridge which resulted in an aesthetic and cost-effective structure. Utilizing a counterweight-assisted design and an integral trunnion, the design/build team created a bridge which is a viable element of the theme park's goal to entertain without sacrificing function or reliability.

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