Heavy Movable Structures, Inc.

SIXTH BIENNIAL SYMPOSIUM

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Doubletree Resort Surfside
Clearwater Beach, Florida

The Temporary Bridge at 17th Street Causeway

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INTRODUCTION

The need for a temporary movable bridge during replacement of the 17th Street Causeway Bridge was an obvious conclusion considering the limited right-of-way, the desire for a straight permanent alignment, and the importance of maintaining four lanes of vehicular traffic at a site considered the "yachting capital of the world". Clearly, movable spans are an expensive investment. With the planned usage of the temporary movable span for only two to three years, the cost appears difficult to jusify. However, when the Florida Department of Transportation realized the potential financial benefit that might come with reuse or high salvage value through resale of the temporary movable bridge, focus was placed on a temporary movable span that could be erected and dismantled for future reuse at other sites.

This paper presents the unique design solution, a temporary Dutch-style bascule bridge, developed for maintaining traffic during the replacement of the existing 17th Street Causeway Bridge in Ft. Lauderdale, Florida. Although the temporary bridge contains over 300m of approaches with many interesting design aspects, this paper will concentrate on the temporary movable span.

DESIGN CRITERIA & PROJECT OBJECTIVES

It is not often that a bridge is required for only two to three years of service at a given site and even less often that a bridge is wanted for use at more than one site. Thus, it is understandable why there are few formal design specifications that guide an owner or design engineer in the development of a temporary bridge such as this. It was necessary to develop a set of goals and objectives for the design that served as a baseline for comparison of alternatives and direction for the design. The following goals and objectives were established as a result:

1. The span should not be cost prohibitive.

2. The span should be capable of easy erection and dismantling. This requires that as much of the span be prefabricated (or precast) as practical. Subassemblies should be manageable and similar in size and weight for handling, transportation and storage.

3. The span should be capable of erection without (or with only minimal) disruption to vehicular and navigation traffic (i.e., the span should be capable of erection in the open position with access from the waterway or temporary bridge approach spans.)

4. Each component or subassembly should be readily accessible for easy handling and erection.

5. The alignment of components and subassemblies should be easily acheived and should be repeatable.

6. The span should meet the geometric requirements of this site and should be versatile and adaptable for reuse at other sites. Thus it should be capable of accomodating typical

horizontal clearances found throughout Florida, unlimited vertical clearance, possible limited underdeck clearance, limited right-of-way, different pedestrian requirements, etc.

7. The span should operate safely and reliably in its initial and future use. Therefore, the design should meet all applicable AASHTO criteria.

DEVELOPMENT

A number of bascule span types were evaluated based on the above criteria from which several, including vertical lift, swing, and floating draw span types, were eliminated by inspection. A conventional double-leaf trunnion bascule with an underdeck counterweight, and two single-leaf bascules with overhead counterweights were evaluated in detail. In the end, a single-leaf configuration was selected over a double-leaf configuration as it offered the following advantages:

* a more efficient structural design (i.e., it requires less overall steel than a double-leaf of the same span length),

* only one set of drive machinery to purchase and maintain (although the drive is more substantial in size),

* less exacting alignment requirements than a double-leaf span,

* a more simplified control system resulting in improved safety during operation with only one moving leaf (i.e., at one point, the existing double-leaf bascule, half of the replacement twin double-leaf bascules and the temporary bascule will be in service at one time),

* improved visibility of the waterway for the bridge operator (i.e., with the bascule pier located on the opposite side of the channel from the control house the open bascule leaf will not block the view of the channel),

* The single-leaf adapts well to an overhead counterweight configuration which provides advantages over a conventional underdeck counterweight by:

    - making the counterweight more accessbile for erection and dismantling,

    - eliminating the need for an expensive enclosed (dry) counterweight pit to prevent the counterweight from pivoting below the splash zone, especially where there is a limited underdeck clearance,

    - increasing the likelihood the temporary bridge would be suitable at a yet to be determined, future site.

A single-leaf Scherzer rolling bascule was compared with a Dutch-style (overhead counterweight) trunnion bascule in greater detail. Both offered similar advantages and disadvantages, but ultimately, the Dutch-style trunnion bascule was determined to have the lower initial cost, despite the greater steel quantity, as the rolling bascule counterweight framing, curved track, and machinery frame unit prices were estimated to be higher due to the greater amount of labor required.

SINGLE-LEAF DUTCH STYLE (OVERHEAD COUNTERWEIGHT) BASCULE

General

The following sections describe the overall configuration and design concept of the Dutch-style bascule and a number of the innovative design solutions used to acheive the design objectives.

The movable span consists of a heel trunnion bascule leaf balanced via an overhead counterweight. The balance frame that supports the counterweight is connected to the bascule leaf by a pair of link arms near the tip of the leaf and is supported on "Hopkins" (overhung) trunnions at the top of a pair of "A" frame towers. The bascule leaf, "A" frame towers, bascule pier roadway deck, drive system, power and control systems are all directly mounted on a common steel support frame. **(See Figure 1.)**

The Dutch-style bascule is similar in many respects to a conventional trunnion bascule with an underdeck counterweight. However, for all practical purposes, the counterweight is shifted parallel to the bascule leaf by an amount that allows the counterweight to swing clear of the roadway deck. **(See Figure 2.)**

The parallelogram, defined by the bascule span geometry (i.e., the four [4] pivot points - heel trunnions, counterweight trunnions, and two [2] link arm bearings), must be maintained in order to assure the proper operation of the leaf.

Similar to the conventional trunnion bascule, proper balance of the bascule leaf is acheived when the unbalance of the bascule leaf closely equals the unbalance of the counterweight (including balance frame) . Furthermore, with a Dutch-style bascule, the gravity line of the counterweight must be parallel to the gravity line of the bascule leaf (where the gravity line is defined as a line that passes through the center of gravity of the element and the center of rotation of the element [e.g., trunnion.])

Link arms maintain the required geometric control (parallelogram) by forcing the upper and lower pivot points at the tips of the span to deflect equally. A parallelogram is always maintained by the link arms, although, the parallelogram varies in shape as the span rotates due to both changing geometry and varying deflection of the main girders. In fact, the left and right parallelograms (in the planes of the left and right main girders, respectively) will vary from each other due to the unsymmetrical configuration and unequal deflections of the main girders.

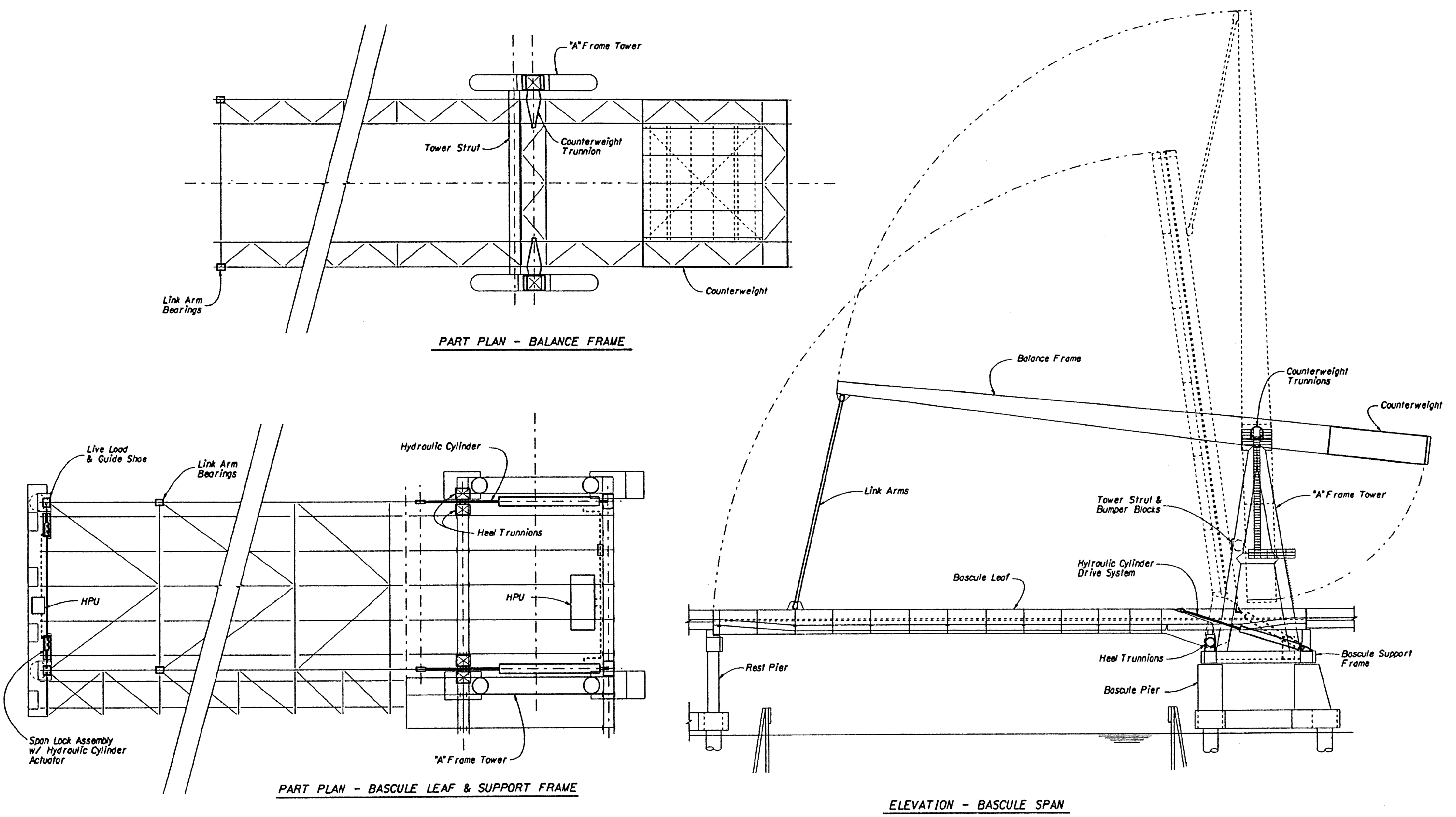
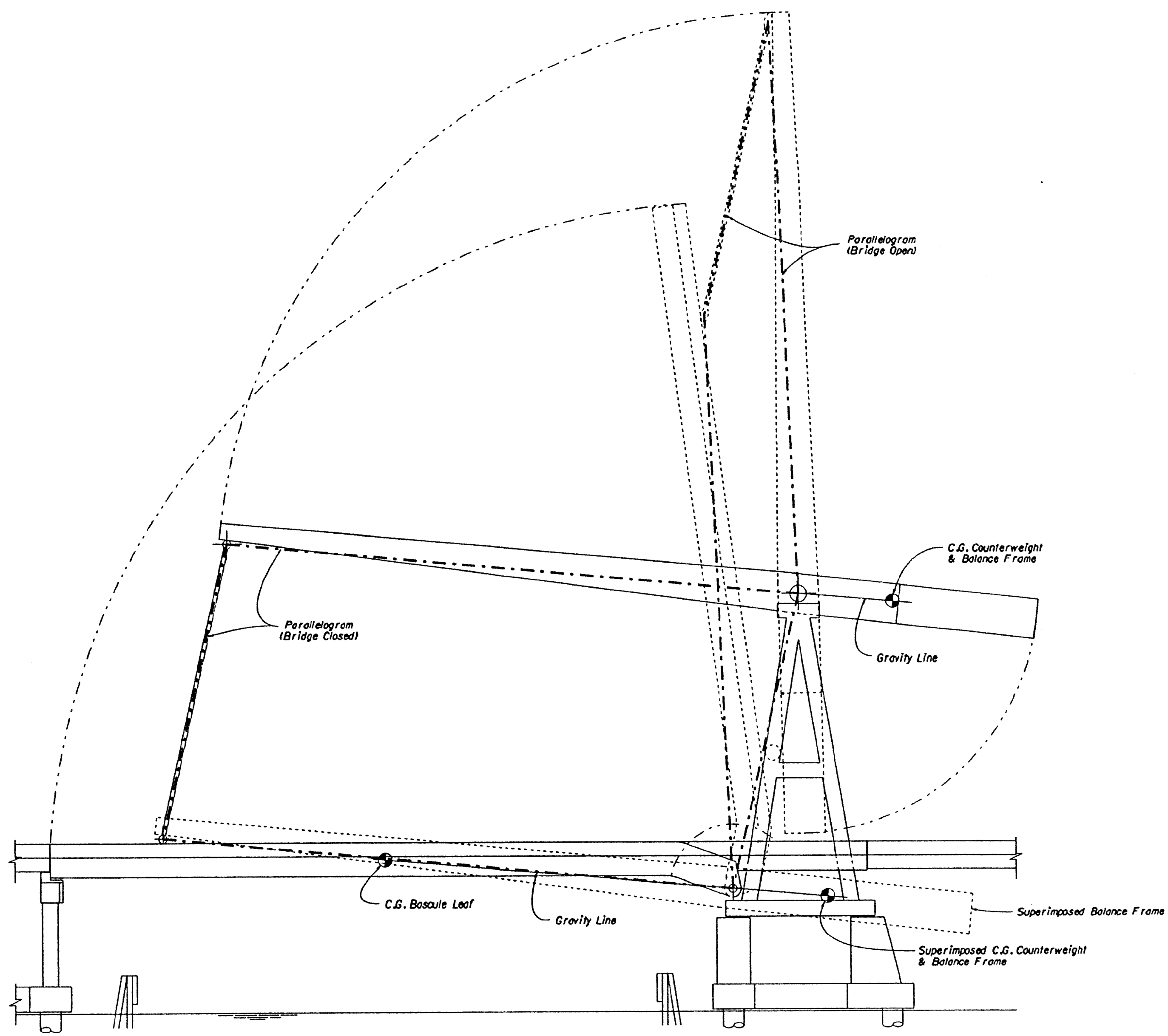


FIGURE 1. BASCULE SPAN ELEMENTS



ELEVATION

FIGURE 2. BASCULE SPAN SCHEMATIC

The link arms must be located near the end of the bascule leaf where deflections and rotations of the span are minimal so as to reduce oscillation of the counterweight and balance frame due to live loads on the bridge.

A bascule leaf span of 40.5m, from heel trunnion to live load shoe, was required to span the 30.48m navigation channel at a 77°28'05" skew angle. The heel trunnion configuration for the bascule leaf and overhung trunnion configuration of the balance frame easily accomodates the 82.5° opening angle used to acheive an unlimited vertical clearance for the navigation channel. The heel trunnion configuration of the bascule leaf permits placement of the trunnion as close to the navigation channel as practical, thus providing the shortest trunnion bascule span length. **(See Figure 3.)**

As a matter of interest, the Scherzer rolling bascule with an overhead counterweight permitted only a slightly shorter span length than the Dutch-style bascule, despite the advantage of the roll. With the center of roll located well above the low member elevation, the span requires additional rotation to clear the channel.

The temporary bridge is required to carry to two 3.3m lanes , 600mm shoulders and a single 1.8m sidewalk across the Atlantic Intracoastal Waterway.

Bascule Leaf, Main Girders & Floor System

A simple framing system with conventional simple shear connections was used for the bascule leaf to facilitate erection and dismantling. **(See Figure 4.)**

A through-girder configuration was selected to provide the lowest overall bridge elevation while providing the same vertical clearance as the existing bridge. Main girders were located as close together as practical, 9.2m on center, to reduce the floorbeam span and width of the balance frame overhead.

Transverse and longitudinal stiffened main girders were used to reduce the weight of the main girders, as the minimum web size was reduced from 16mm to 10mm. Although, this may not result in the least overall plate girder cost, considering increased labor costs associated with the additional welding, the weight savings on a bascule span contributes also to savings in the counterweight, balance frame, link arms, towers, machinery, etc.

Bracing of the main girder compression flange is traditionally accomplished via knee braces on the inboard side of the girders at each of the floorbeams. However, inboard knee braces, would add to the overall structure width and complicate framing details. A lateral stability analysis of the main girder-floorbeam system revealed that an oversized transverse stiffener on the outboard side of the girder would adequately brace the compression flange. The transverse stiffener was sized to provide sufficient stiffness to prevent lateral instability of the girder at each of the floorbeam locations, thus reducing the buckling length and permitting the use of higher allowable stresses. The oversized stiffener allows the girder to be fabricated using common fabrication techniques and avoid

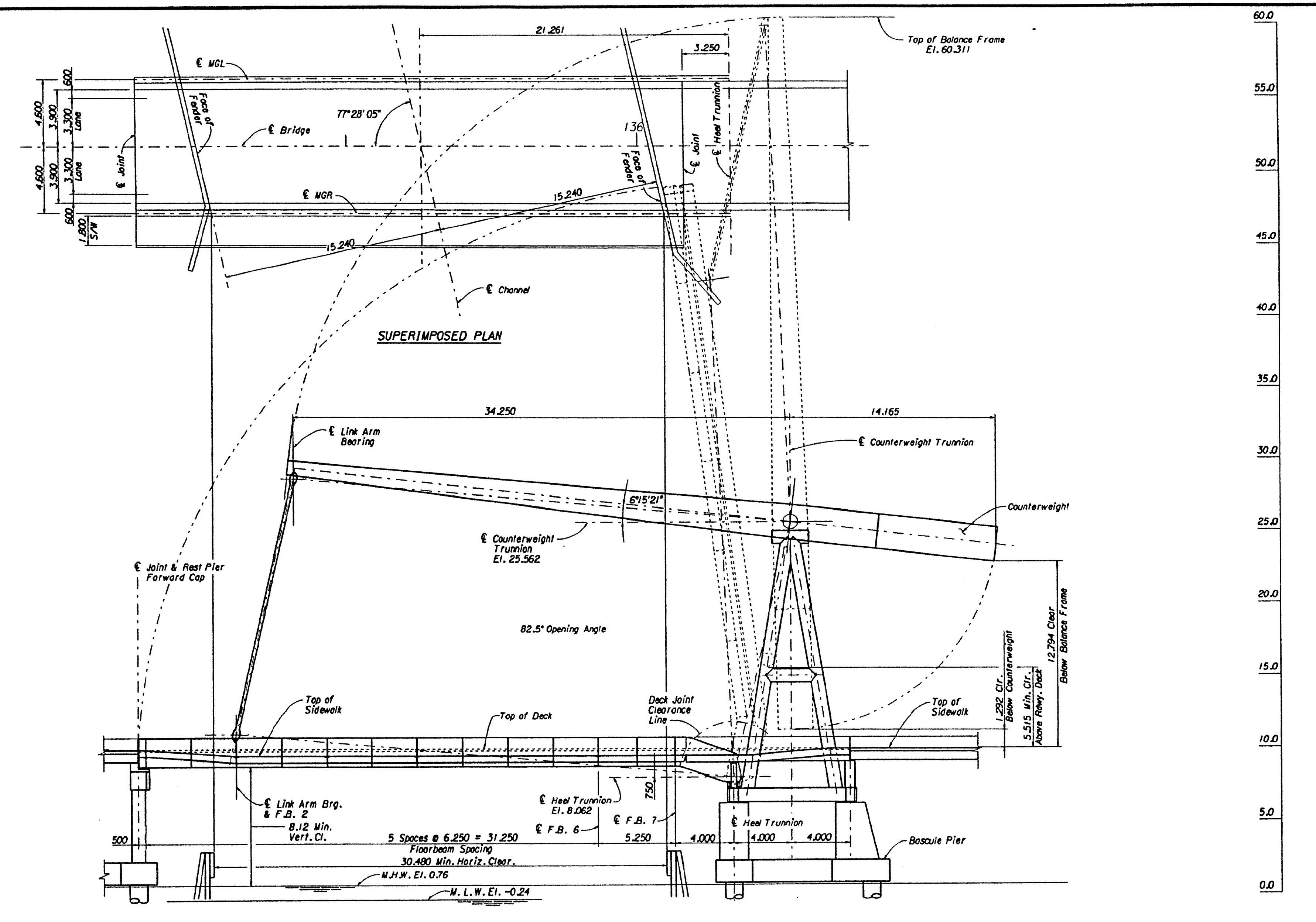


FIGURE 3. BASCULE SPAN CLEARANCE DIAGRAM

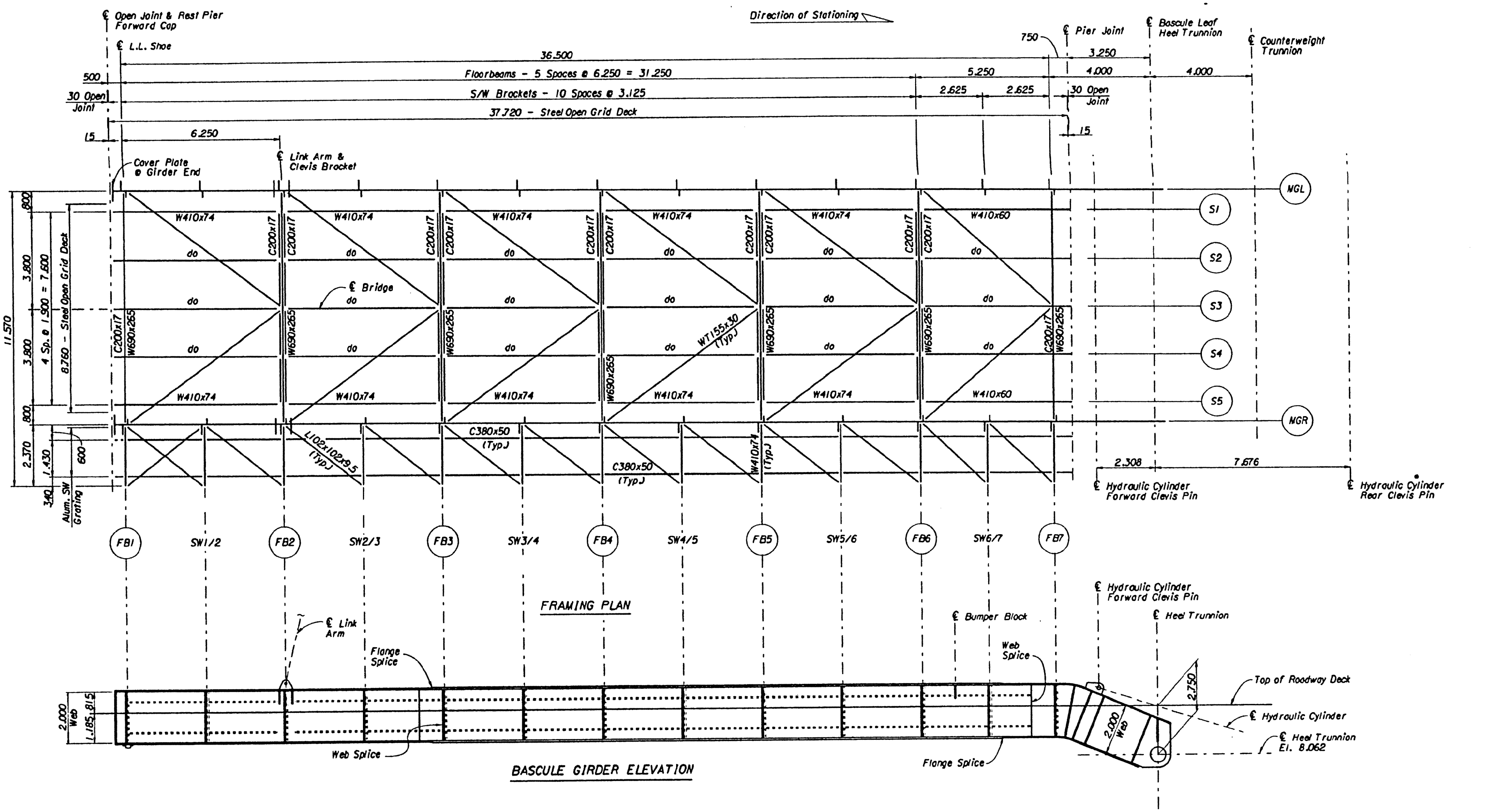
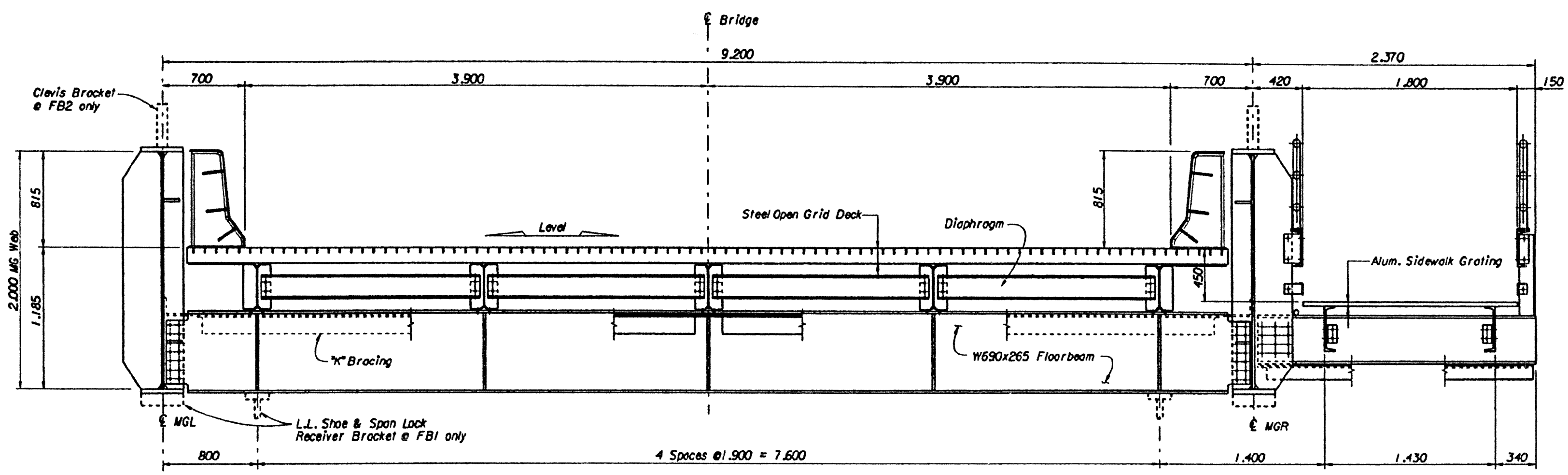


FIGURE 4. BASCULE LEAF FRAMING PLAN & GIRDER ELEVATION



SECTION THRU BASCULE LEAF
AT FLOORBEAMS
(Typical FB2 Thru FB7, FB1 Similar)

FIGURE 5. BASCULE LEAF TYPICAL SECTION

complicated details.

The floor system consists of simple framed rolled steel floorbeams and stringers supporting a 5 Inch- 4 Way steel open grid deck. Floorbeams are spaced at 6.25m and are flush with bottom of the main girders to reduce the structure depth. Stringers, spaced at 1.9m on centers and braced over the floorbeams with end diaphragms, span simply supported from top to top of floorbeams. The five (5) stringers, end diaphragms, open steel grid deck and steel traffic barrier sections can be preassembled and lifted in to place or removed as a single unit facilitating erection and dismantling. **(See Figure 5.)**

"K" bracing was used to provide the lateral bracing system for the leaf. In addition to providing bracing against transverse wind loads, the K-bracing serves to resist the floor system dead loads with the bridge in the raised position. With most trunnion bascule leaves with an underdeck counterweight, the floor system dead loads are resisted primarily by a rigid counterweight. Without the rigid counterweight at deck level, as with a Dutch-style bascule, these loads must be resisted solely by the bracing system. "K" bracing efficiently carries the loads in tension to the main girders, permitting the use of the higher allowable axial stress available to a tension member. The bracing members frame in to the top flange of the floorbeam and main girder web via gusset plates.

The sidewalk for the bascule leaf is cantilevered outboard the main girder. The oversized stiffeners used to brace the compression flange permit the use of a simplified, bolted moment connection for the cantilevered brackets in lieu of more complicated tie plate connections. The cantilevered brackets are located at each floorbeam and at intermdeiate locations mid distance between the floorbeams.

As the sidewalks are outboard the main girders and only 1.8m wide, there was no need to design the sidewalk grating or framing for incidental or service wheel loads. As a result the sidewalk decking and framing are relatively lightweight.

The symmetrical details of the leaf and main girder capacity permits the attachment of a similar sidewalk to the opposite side of the leaf.

Balance Frame, Link Arms & Counterweights

The balance frame main girders, trunnion girder and counterweight girder consist of open-tub box girders. Box girders were selected over plate girders because of the large combined shear and bending loads, increased lateral stability and torsional resistance provided; open-tubs were selected over closed box sections because of the more common fabrication techniques required. Diagonal bracing between the top flanges complete the box section. Thin cover plates are bolted across the top flanges to close off the interior of the boxes from birds and weather. Similar to the basccule leaf main girders, transverse and longitudinal stiffeners were used to reduce the web thickness and thus overall weight of the balance frame. A longitudinal stiffener was similarly used along the bottom (compression) flange to reduce thickness and weight. **(See Figure 6 & 7.)**

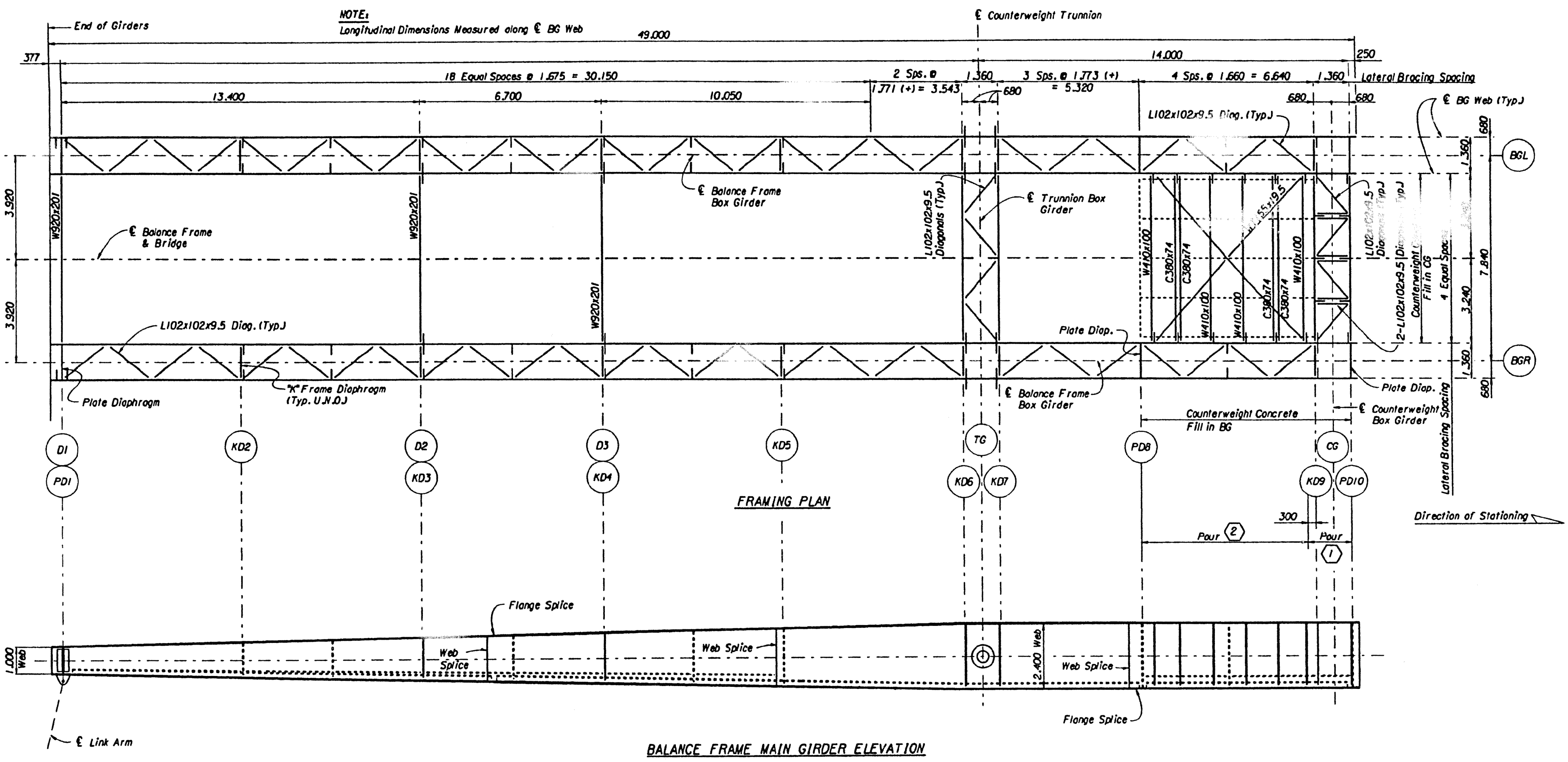
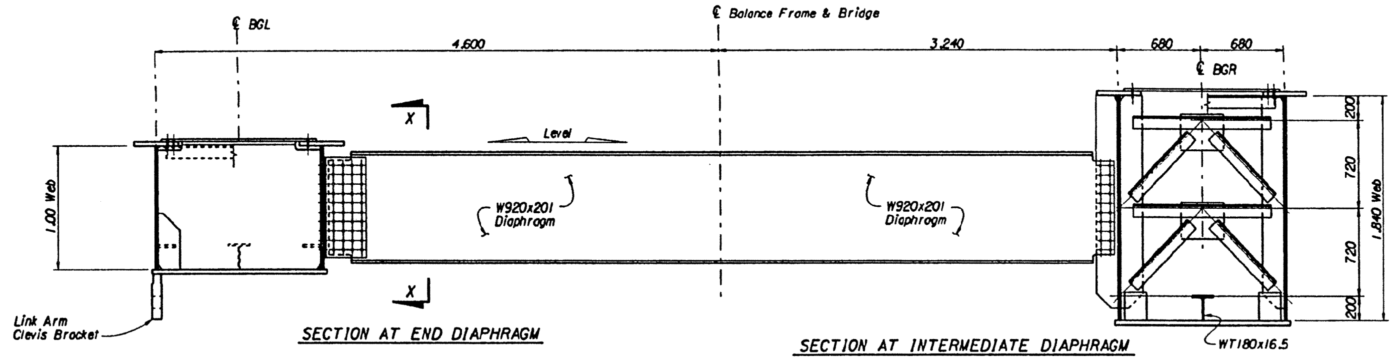


FIGURE 6. BALANCE FRAME FRAMING PLAN & GIRDER ELEVATION



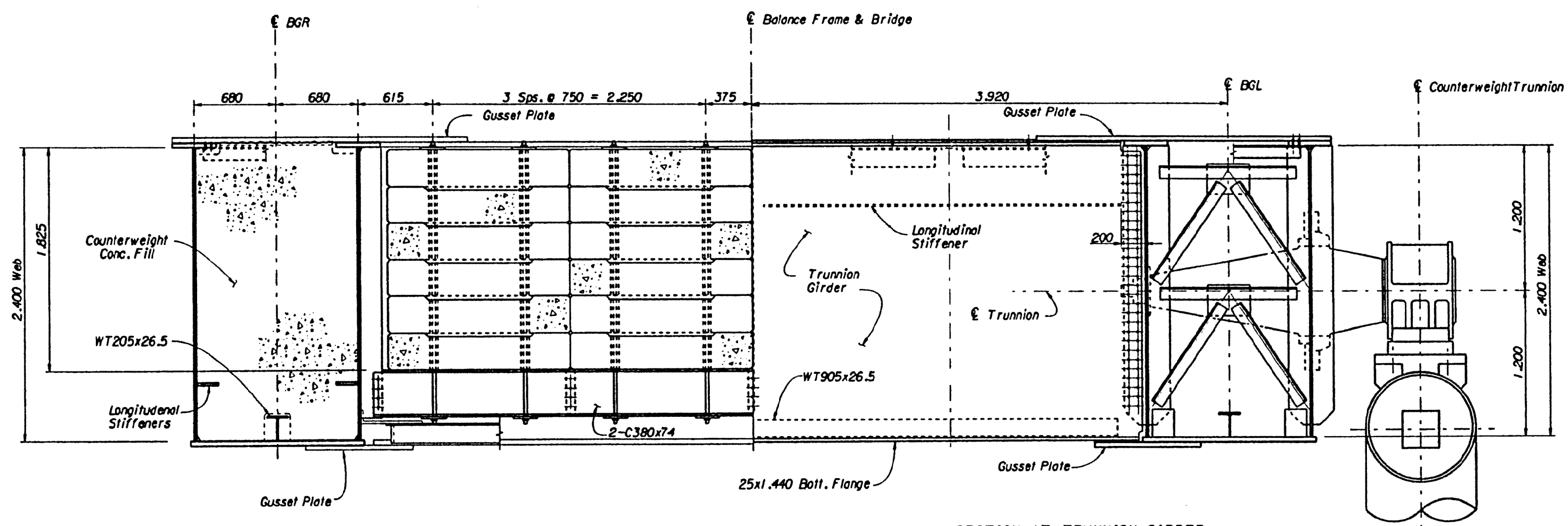


FIGURE 7. BALANCE FRAME TYPICAL SECTIONS

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Rolled steel W-shape diaphragms span between the main girders forward of the trunnion. The diaphragms act to share the load between the two main girders and lower somewhat the stresses in the girder which receives the greater portion of load due to the unsymmetrical bascule leaf configuration.

The balance frame is oriented nearly vertical with the bridge in the fully open position which facilitates erection and dismantling as the balance frame can literally hang from the "A" frame tower in a stable configuration.

The link arms consist of steel pipes pin connected at the ends via clevis bracket assemblies. The clevis brackets welded to the main girders of the balance frame and bascule leaf contain plain spherical bearings to accomodate any slight misalignment between the bascule leaf and balance frame and allow for lateral displacement of the balance frame relative to the bascule leaf caused by lateral wind loads. Maintenance free bearings are used to reduce the need for maintenance personnel to walk to the tip of the balance frame to lubricate the bearings. The link arm length can be adjusted to the exact required center to center distance via shims at the ends of the link arms.

Counterweight is provided in three (3) ways:

1. cast-in-place concrete poured between the webs of the main girders and counterweight girders,

2. precast reinforced concrete planks, keyed together and anchored to steel framework between the main girders via posttensioned threadbars (The precast planks bear on the counterweight girder as the span rotates to full open.),

3. steel ballast plate bolted to the top of the counterweight girder for fine adjustment of the balance.

The precast planks make up for approximately half of the counterweight concrete and provides for easier erection and dismantling of the balance frame (i.e., more manageable weight elements.) Additional internal bracing and stiffening of the counterweight girder permit the placement of the cast-in-place concrete without falsework.

"A" Frame Towers & Support Frame

The balance frame is supported atop a pair of "A" Frame shaped towers fabricated from 900mm round steel tubing. Each tower is located outboard the basccule leaf main girders. The sidewalk is diverted outboard the tower over the bascule pier. The "A" Frame configuration was selected to provide greater stability in the longitudinal direction against large wind loads acting on the bascule leaf and balance frame with the span fully open. A longitudinal strut at approximately mid height of the tower and between the inclined tower legs provides additional buckling resistance.

An additional strut, fabricated from the same steel tubing as the tower legs, spans between the two "A" Frame towers creating a rigid frame. The rigid frame was required to resist transverse wind loads on the balance frame and towers. The strut is placed between the forward inclined legs of the tower at 5.515m clear above the roadway deck. The strut is located to provide a bumper block mounting location in line with the bascule leaf main girders and to provide nominal clearance to the balance frame with the span fully open.

Round tubing is used for the towers as it offeres the required low slenderness, high compression capacity for the column members while also providing adequate shear and bending capacity for the rigid frame and relatively clean and simple welded connection details.

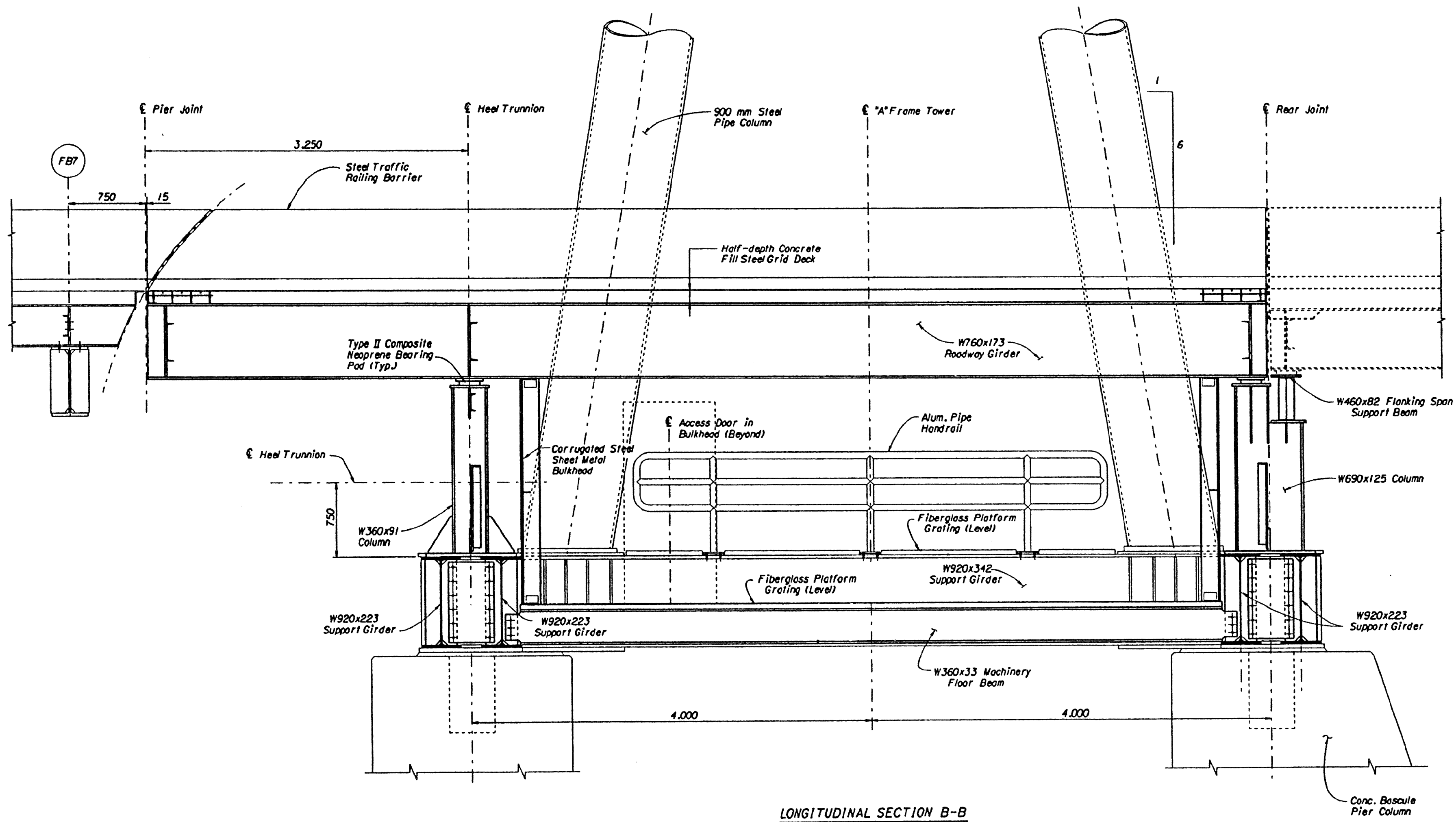
The bascule support frame serves as a common base for support and alignment of the numerous components that make up the span including the bascule leaf heel trunnions, "A" frame towers, roadway deck over the bascule pier, flanking span, hydraulic cylinders, and machinery room that houses the electrical equipment and hydraulic power unit below the roadway deck.

The support frame is mounted on a simplified concrete bascule pier which could vary somewhat from site to site depending on the geometrics, foundation requirements, ship impact and scour considerations, etc. Because of these varying conditions and the difficulty of relocating large concrete footings and columns, pile foundations, etc. the bascule pier is considered "disposable". The support frame can be dismantled and shipped to the next site and serve as the common base for restablishment of the span. **(See Figures 8, 9 & 10.)**

The framework for the bascule support frame consists primarily of main longitudinal girders in line with the "A" Frame towers. A forward cross girder (centered at the bascule leaf heel trunnions) and a rear cross girder (spaced away from the forward cross girder to provide the required hydraulic cylinder operating geometry) span between the main longitudinal girders. The longitudinal girders and cross girders consist of pairs of rolled steel shapes tied together with diaphragms. Large gusset plates at the intersections of these girders provide rigid framing for the framework. The main longitudinal girders bear on and anchor to the top of the concrete bascule pier columns.

The inclined legs of the "A" Frame towers bolt to the the top of the support frame main longitudinal girders just inside the cross girders. Thus, the main longitudinal girders serve as a tension tie between the inclined legs.

The roadway deck over the bascule pier consists of rolled steel stringers at 1.9m on center similar to the bascule leaf. The roadway stringers support a grid reinforced concrete deck which also serves as the roof over the machinery room. The stringers are supported on rolled steel columns from the cross girders of the support frame. The roadway stringers cantilever 3.25 m beyond front cross girder of the support frame placing the joint between the bascule leaf and pier forward of the heel trunnion. This results in the bascule leaf deck rotation above the roadway deck and avoids breaks in the pier that will allow weather into the machinery room area.



LONGITUDINAL SECTION B-B

FIGURE 8. BASCULE SUPPORT FRAME LONGITUDINAL SECTION THRU ROADWAY

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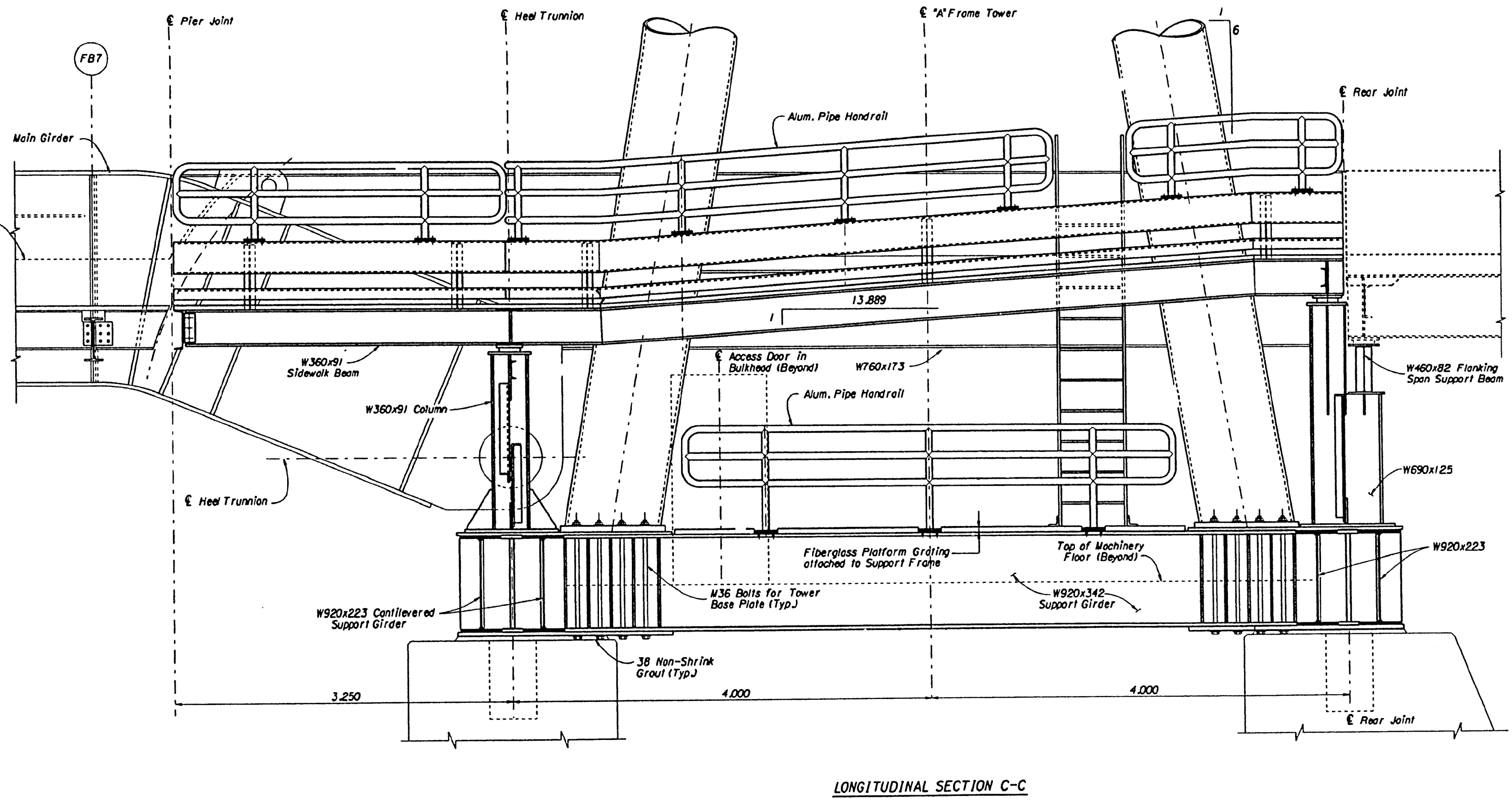
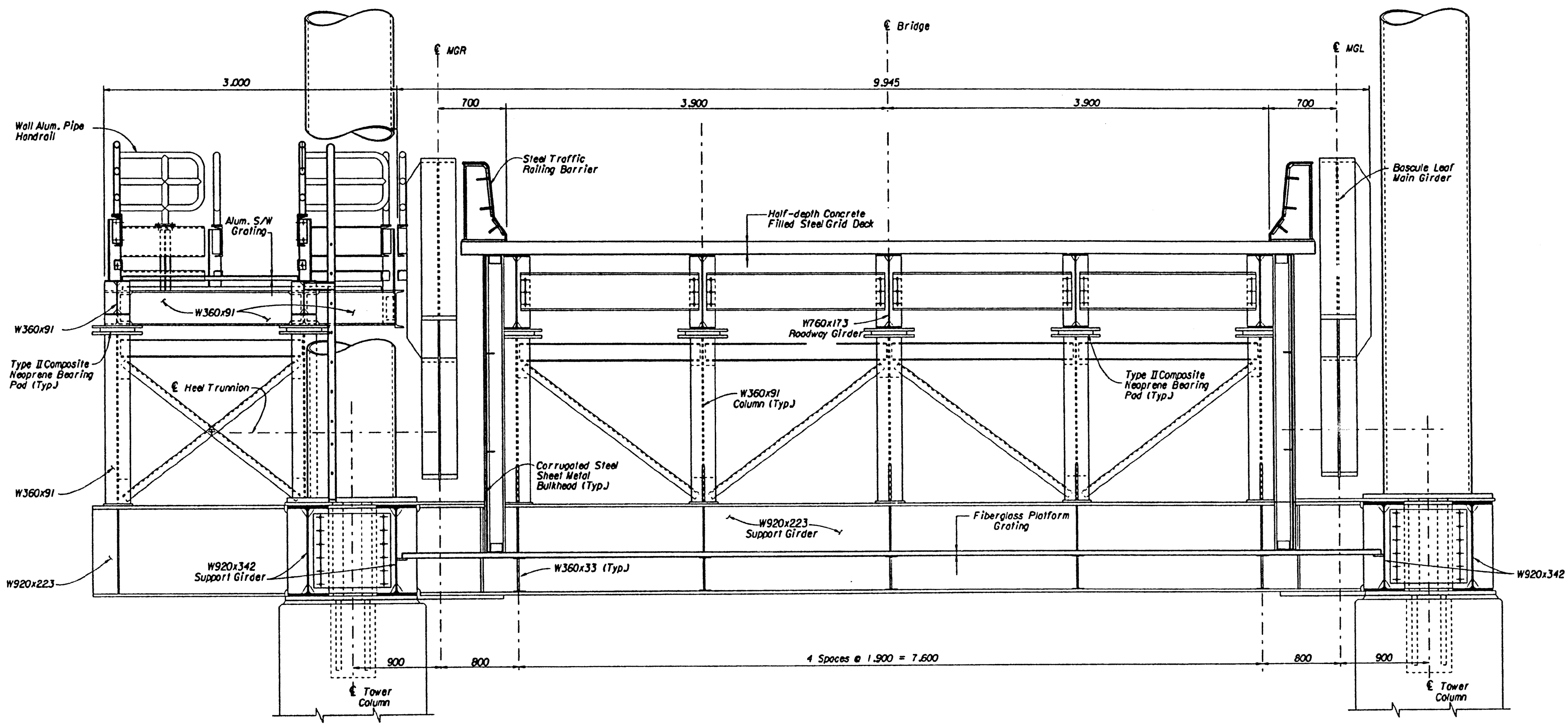


FIGURE 9. BASCULE SUPPORT FRAME LONGITUDINAL SECTION THRU SIDEWALK



TRANSVERSE SECTION A-A

(LOOKING BACK STATION)

FIGURE 10. BASCULE SUPPORT FRAME TRANSVERSE SECTION

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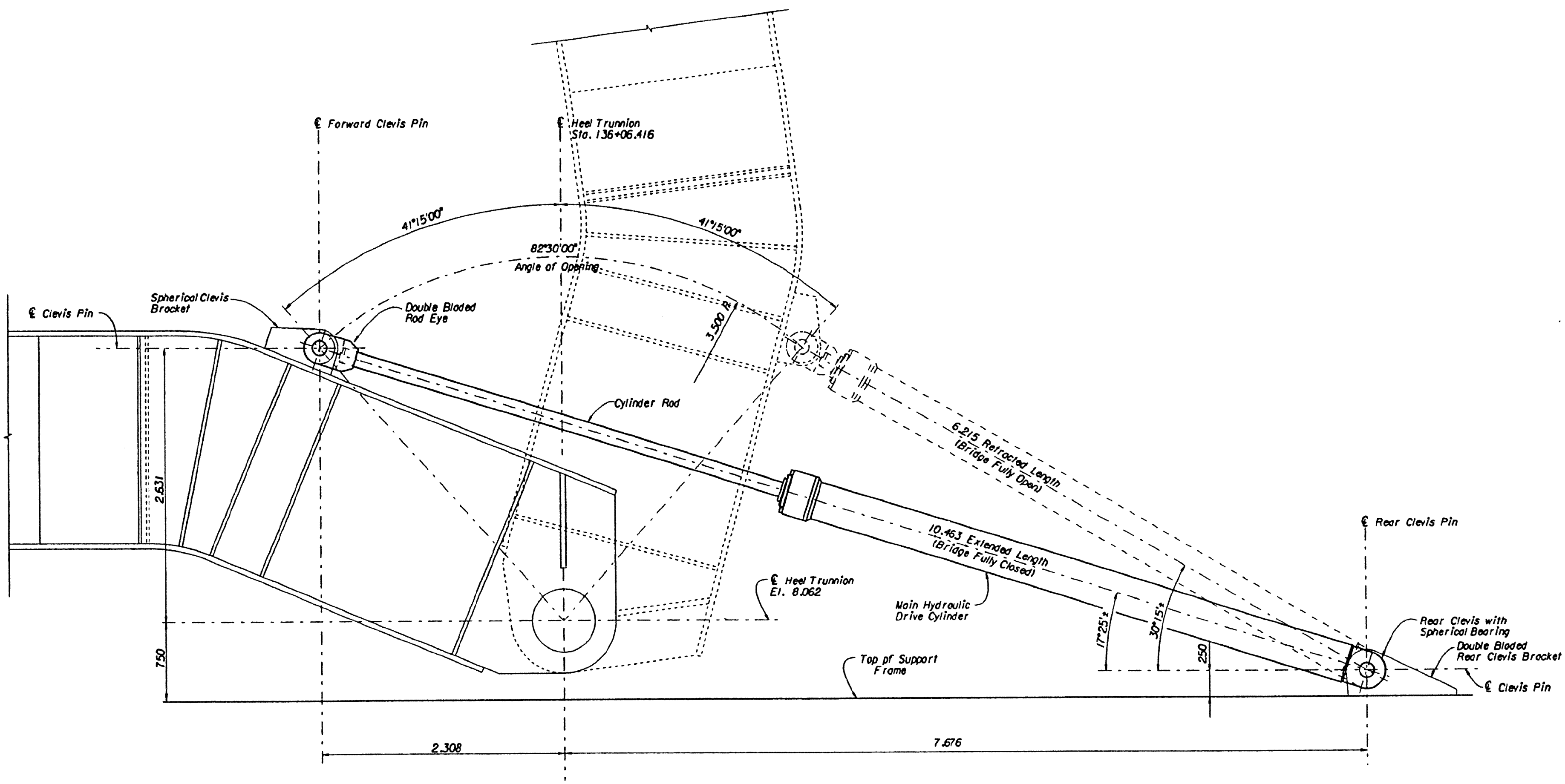

MAIN HYDRAULIC CYLINDER ELEVATION

FIGURE 11. HYDRAULIC CYLINDER GEOMETRY

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The machinery room provides a 2.25m minimum working overhead clearance over a fiberglass platform grating. A solid fiberglass top plate was added to collect small amounts of hydraulic fluid in the event of a minor leak. The machinery room is walled in with corrugated steel sheet metal bulkheads; ladders and doors are provided for access.

Operating Machinery

The span is driven by a pair of 320mm bore, clevis mounted, mill-type hydraulic cylinders. Unlike most conventional trunnion bascule spans with hydraulic cylinders in the United States, the cylinders on this bridge are arranged to pull the span open (i.e, with the bridge fully closed, the cylinders are extended and with the bridge full open the cylinders are retracted.) **(See Figure 11.)**

This arrangement provides an efficient cylinder design by eliminating buckling of the cylinder rod as a primary concern. The cylinder length is shortest when the span is full open and is subject to the greatest compressive loads due to wind. The cylinder is at its greatest length when the bridge is full closed and compressive loads are a minimum. With buckling of the cylinder rod no longer a primary concren, maximum operating and holding pressures on the blind end of the cylinder can be calculated using a smaller rod. As a result, a smaller cylinder can be used to provide the same force as a larger cylinder with a larger rod. This savings impacts the entire hydraulic power system as less fluid flow is required with the smaller cylinder.

The cylinders are clevis mounted with plain spherical bearings to permit slight misalignment in the initial cylinder installation and to allow for float in the span during operation.

The bascule leaf is supported by simple trunnions at the heel of each of the two main girders. The relatively small (305mm diameter journal) trunnions are each supported on a pair of trunnion bearings with bronze sleeve bushings. Each of the two trunnion bearings are mounted on a common weldment which bolts to the support frame forward cross girder facilitating shop alignment of the heel trunnions.

The balance frame is supported on a pair of "Hopkins" (overhung) trunnions. The counterweight trunnions frame into the dual webs of the balance frame box girders similar to how a "Hopkins" trunnion frames into the main girder and trunnion girder of a traditional Florida bascule. The torsional moment caused by the overhung trunnion is resisted primarily in bending by the trunnion box girder. However, the torsionally stiff main girders transfer a portion of the overhung moments to the counterweight girder and diaphragms to reduce the loads in the trunnion girder.

The trunnion bearings for the counterweight trunnions are much larger (530mm journal diameter) than the bascule leaf heel trunnions primarily due to the large counterweight dead loads and single bearing configuration. Similar to the heel trunnions the counterweight trunnions utilize bronze sleeve bushings. Three-piece eccentric assemblies have been provided at the inboard ends of the trunnions to facilitate alignment of the counterweight trunnions.

Span locks are provided at the tip of the bascule leaf primarily to prevent uplift resulting from an upward wind on the bascule leaf or balance frame. The span locks are driven via a common hydraulic power unit.

Combination live load and span guide shoes are provided to assure the bascule leaf rests properly aligned with the approach spans.

CONCLUSION

The Dutch-style trunnion bascule exhibits a combination of unique characteristics that should make it an effective temporary movable span, including:

1. a number of smaller manageable, preassembled (or precast) components or subassemblies that facilitate erection and dismantling,
2. a configuration permitting access and stability for erection and dismantling ,
3. components that permit the alignment to be readily acheived and repeatable (e.g., a rigid steel support frame which serves as a common base for the entire bascule span, link arms and clevis mounted cylinders which permit adjustment and an acceptable amount of misalignment, etc.),
4. a design readily adpatable for reuse at numerous other sites (due to the long available span length, overhead counterweight, capability of adding a sidewalk) and,
5. a safe, and reliable design.

In fact, the bascule span could just as well function as a permanent bridge at another site.

The temporary bridge is currently in construction and is to be in service for approximately two years until the first half of the 17th Street Causeway Replacement Bridge is constructed, after which, the span will be available for use at another site. And if you believe what I'm telling you - have I got a bridge to sell you!!!