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Lagoon Pond Drawbridge Overview

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TAMPA, FLORIDA

Introduction

Figure 1: Bascule Span

Parsons was selected by the Massachusetts Department of Transportation (MassDOT) to design the replacement of this movable bridge on Martha's Vineyard with a project cost of just under $40 million. The existing single-leaf bascule structure was built in 1935, and was at the end of its useful life. A temporary bridge was constructed, and remained in service until the replacement structure was opened to vehicle traffic in 2016.

The structure is located on Beach Road, a heavily traveled connection between Tisbury and Oak Bluffs. With a ferry terminal within two miles of the bridge on the Tisbury side, and the Martha's Vineyard Hospital within less than a quarter mile of the bridge on the Oak Bluffs side, replacement of the structure was a high priority for the community and MassDOT. The total length of the new bridge is about 350 feet, with a 50-foot-long, single-leaf bascule span utilizing a fixed rotating counterweight.

Sight distance for marine traffic was also a key issue. The existing bridge had been supported on multiple timber pile bents with bracing between, blocking the view of oncoming marine traffic. Additionally, an adjacent beach area created a "dog-leg" approach to the bascule span from the harbor side, which interfered with sight lines. Parsons' design offered fewer approach spans, with concrete pile bents, and shifted the location of the bascule span 50 feet to the Tisbury side, making a significant improvement in sight lines for marine traffic.

Furthermore, the project included a new marine fender and lighting system to meet current U.S. Coast Guard requirements, as well as the design of a new bridge tender's house that includes provision for a CCTV system to monitor marine traffic as it approaches the bridge.

Aesthetics

Figure 2: Rendering of preferred alternative

Aesthetics was a key concern for the owner and a local community group that was formed, the Lagoon Pond Drawbridge Committee (LPDC), to help guide the vision of the project. The LPDC wanted a structure that fit well into the surrounding natural environment and the local architecture, including the many stone buildings on Martha’s Vineyard. Based on these criteria an elegant stone structure was designed with 360 degrees of windows. A concrete and steel BR-2 railing was used on the superstructure at the edge of roadway to keep vehicles off the roadway. This allowed for a decorative steel pipe rail with pickets to be used at the edge of the sidewalks. The approach piers where open pipe pile bents with concrete caps. The abutments were built with a stone form-liner that replicated the stone bascule pier. On the southwest quadrant of the project a park was created including walking paths with lighted bollards, local plantings and seating areas. There were also walkways built that allowed pedestrians to safely cross from one side of the bridge to the other underneath the structure and provided enhanced pedestrian access to the adjacent beach and recreation areas.

Figure 3: New Park under Construction

Moving the primary navigation channel

Another major goal of the project was to move the existing navigation channel to the west to provide a better approach to the bridge for boaters. Since the time the original bridge was constructed there had been significant changes to the shore line geometry due to sand build-up in the Eastville Point Beach area northeast of the bridge. These changes created a difficult “dog-leg” for mariners to maneuver around.

The temporary bridge was constructed with a significantly longer bascule span than the original bridge with the intention of allowing the channel to be moved to the west. However, due to the low angle of opening of the temporary structure, the amount the channel could be moved was limited. At the request of the Owner, Parsons looked at several options and bascule span lengths and arrangements to provide the desired channel location without impacting access during construction of the new bridge.

Figure 4: Aerial view of the bridge during construction.

It was determined that a single span bascule of approximately one hundred feet in length would be required to provide the optimal channel location in the final condition while maintaining marine traffic during construction. A bascule span of this size would add significant cost to the project. The Parsons team came up with an alternate solution that would achieve the desired goal without driving up the costs. It was determined that a new 50’ bascule span could be built in the preferred location with a fixed span adjacent to the temporary bascule span. The superstructure of the new fixed span would be left off until the last stage of construction. This allowed mariners to travel normally through the original channel throughout construction. Once the bascule span, other approach spans and approach roadways were complete and the bascule span had been fully tested and was ready to be put into service the final fixed span superstructure was completed during a brief channel shutdown that was coordinated with the community, Coast Guard and local harbormaster.

This construction staging worked very well and the bridge was completed with minimal impacts on mariners and at a considerable cost savings when compared to the longer span alternatives.

Providing two options for navigation below the bridge

Figure 5: Existing Bridge showing existing channel

The design team was able to reduce the number of bridge opening by replacing the existing single marine channel with two separate channels for mariners to choose from. The channel under the existing bascule span offered 15’-0” of vertical clearance in the fixed position and unlimited vertical clearance in the open position. A marine clearance study was prepared that considered navigation issues, frequency of bridge openings and vessel heights and their effect on the number of bridge openings required. The amount of vertical clearance in the fixed position was expected to be reduced by as much as two feet over time due to the effects of global warming and predictions of sea level rise.

The structure depth of the bascule span was optimized to provide the greatest possible clearance. However, the depth of structure of the bascule span was approximately twice that of the approach structure. In order to avoid steep grades on the approaches or impacting the land on either side of the bridge with longer approaches it was determined that two marine channels would be delineated with a marine lumber fender system; one under the bascule span for taller vessels and one under the adjacent fixed span, in the location of the previous channel, for the smaller vessels. The two channel option that was selected provided a minimum vertical clearance of 19’-0” under the fixed span of the bridge adjacent to the bascule span which still offered 14’-8” of vertical clearance in the closed position and unlimited vertical clearance in the open position.

Seismic Demand Requirements

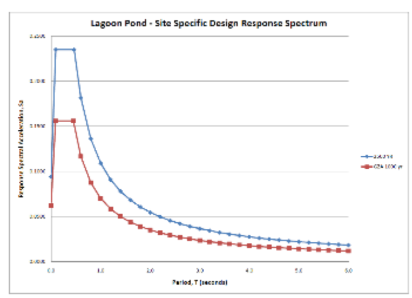


Figure 6: Seismic Design Response Spectrum

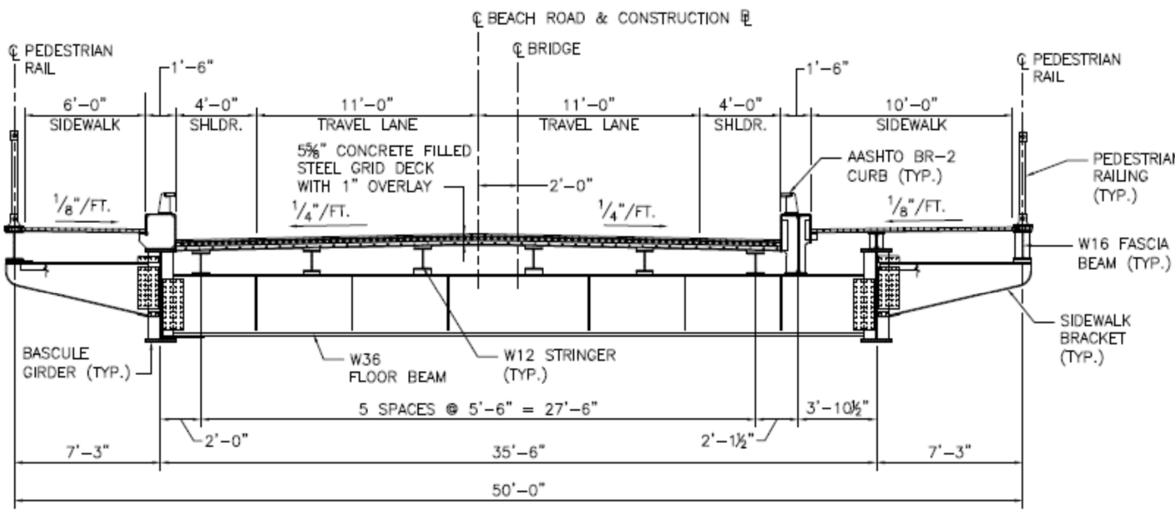
The owner wanted to ensure that the bridge perform well under seismic conditions without driving up costs unnecessarily. Once the bridge span configuration and basic dimensions were determined the design team created a computer model of the bridge in order to evaluate different seismic load cases. The 1000 year and 2500 year seismic events were modeled using SAP 2000. The bridge period, deflections and longitudinal forces were determined and compared for each load case. This information was presented to the State Bridge Engineer who determined that the 1000 year return period was appropriate for the structure.

Steel framing of the bascule span

The bascule span is not symmetrical due to the requirement to have a six foot sidewalk on the north side of the bridge and a ten foot sidewalk for both pedestrians and bicyclists on the south side of the bridge. The framing arrangement that was selected consisted of two main bascule girders spaced 35'-6" on center with floor beams and stringers between the bascule girders and 7'-3" cantilevered sidewalk brackets outside the bascule girders to support the sidewalks.

Figure 7: Bascule span lifted into place

The ten foot sidewalk was created by introducing a special longitudinal sidewalk girder on top of the floor beams. The sidewalk girder support the BR-2 railing and curb plate and provided a load path for any vehicle impact loads back to the main girders. The stringers support a concrete filled steel grid deck with an overlay wearing surface. There is a five foot diameter by one inch thick steel rotating trunnion girder between the bascule girders and the centerline of bearings. The rotating trunnion girder has internal diaphragms that support the inboard end of the trunnions for each girder. At the



BASCULE TRANSVERSE SECTION
SCALE: ¼" = 1'-0"

counterweight end of the span there is a 9'-3" long by 7'-11" deep steel box between the girders that holds the counterweight material, including the adjustable balance blocks. The counterweight box has access to the adjustable balance block chambers with sliding doors on the end of the bridge.

Open bascule pier

The geotechnical conditions in the vicinity of the bridge consist of very deep sand layers. Borings were advanced to more than 165 feet below grade without finding a hard bottom.

A large counterweight pit was not desirable due aesthetics of the large pit and the impacts to the channel bed. An open bascule pier was designed to allow the bascule superstructure to swing through. This allowed the bascule pier to be only as large as required to accommodate the mechanical and electrical equipment necessary to operate the bridge. An aluminum cut-off wall was added between the bascule span superstructure and the machinery room to prevent unauthorized access and protect the machinery and electrical systems.

Support of the tail locks

Since there was no counterweight pit for the bascule span superstructure that also meant there was no backwall to support the tail end of the bridge in the closed position. Supporting the tail end of the bridge was critical as there would be live load on the structure both behind and forward of the centerline of rotation. The solution was to provide tail locks to fix the rear of the bridge in the closed position. The pier closest to the tail of the bascule span superstructure was too far away to support the tail locks. A tail lock support frame was designed to support the tail locks. The tail locks were driven by machinery located inside the machinery rooms with a shaft that exited the back of the machinery room through a hole in the wall. The tail lock support structures we designed to be extremely robust with very little deflection. The designer utilized a rigid steel skeleton support structure that was anchored to the bascule pier with deep anchor bolts. The structure was then encased in concrete.

Figure 8: Tail Lock Support Structure

General Machinery Arrangement

The Lagoon Pond single leaf bascule is equipped with cantilever trunnions which are part of a trunnion girder support system for the leaf. The trunnions are supported in spherical bearings. There are no racks and pinions or open gears and the span drive machinery directly drives the trunnions. Tail locks are used rather than toe locks. Two machinery rooms are provided adjacent to each trunnion. Each machinery room contains a trunnion shaft and bearing, span drive machinery and the tail lock drive machinery. The North machinery room is larger than the South and in addition to the machinery, houses electrical and control system equipment including a generator. The span drive

Figure 9: View of the counterweight section of the bascule girder with cantilever Trunnion Shaft and hole for the Tail Lock Receiving Socket

motor over speed switch and the span limit switch are also located in the North machinery room. The limit switch is driven by a worm speed reducer connected the primary reducer output shaft, opposite the drive end.

Together the North and South span drive machineries provide the torque capacity to drive and hold the leaf against the maximum resistances specified by AASHTO. There is no provision provided to drive with only either the North or South machinery although it is possible against reduced loads.

There are two redundant electric motors connected to each span drive machinery. Either the inboard motors or the outboard motors are used to drive the machinery system. The bridge operator can select between two flux vector drives. Each flux vector drive is connected to two span drive motors in parallel, one in the North machinery room and one in the South. This arrangement provides simple load and torque sharing with a minimum of switching devices. Two systems are provided for redundancy.

The generator is an alternate source of power and provides power to the control system and flux vector drives to drive the leaf. The generator is sized to operate the span at full speed. Gates and tail locks can also be operated by the generator.

Tail Lock Machinery

Single leaf bascules are typically equipped with toe locks. The toe locks normally transmit no load unless there is an operational error where raising the leaf is attempted with the locks still driven to secure the span in the fully closed position. Tail locks were provided due the "rear break in floor" of the bascule span deck, which allows live load to be applied to the deck on the counterweight side if the trunnion. The tail lock resists this load and transmits it to the bascule pier, in addition to providing the physical safety interlock. The two tail locks consist of lock bars, guides and receiving sockets at the tail of the bascule girders. Each lock bar is directly driven by a crankshaft and connecting rod which are part of a combined assembly with the guides and lock bar. The crankshafts are capable of rotating 360 degrees without any physical interference, in the event of a limit switch failure. Each tail lock is driven by a 5 HP motor connected to a parallel shaft gear reducer with a spiral bevel input, located in each machinery room. Floating shafts with single engagement couplings connect the crankshafts to the gear reducer output shafts. The reducer ratio is 336:1 and it requires 12 seconds to drive or retract the lock bars.

The tail locks are designed to lift the counterweight approximately 1/8 inch to create a positive reaction. This prevents any movement or pounding at the tail lock due to live load passing on to and off of the bascule span. An additional benefit is that the reaction created at the tail is that it induces a reaction at the live load bearing at the toe.

Figure 10: Tail Lock Connecting Rod, Crankshaft and bearings

This prevents any movement due to live load at the toe bearing as well. When the leaf is in the closed position with the tail lock driven, positive reactions exist at all points of support. These reactions remain positive during all design live load conditions.

Trunnion Girder and Trunnion Arrangement

A circular trunnion girder with cantilever trunnion shafts is used to support the lagoon pond bascule span. All dead and live load from the leaf is transmitted into the bascule girders, then into the trunnion hubs, shafts and bearings. Each trunnion shaft is supported in spherical bearings to accommodate the static and dynamic deflections of the trunnion girder as the magnitude of the load and the direction of the load changes with respect to the leaf during a bridge opening. The trunnion girder transmits the moment created by the trunnion bearing reaction and the distance between the trunnion bearings to the bascule girder, about 2 feet.

Figure 11: Trunnion Girder between bascule girders visible with leaf in the raised position.

The trunnion girder with cantilever trunnions enables a large angle of opening by eliminating trunnion columns inboard of the bascule girder. The space typically used for the clearance around inboard trunnion columns is available for more counterweight volume. Keeping the distance between the trunnion and the tail end of the counterweight short enough to remain above mean high water when the leaf is open is the key to eliminating the need for a counterweight pit and large bascule pier. Locating the span drive machinery outboard of the bascule girders does not require enlarging the limited space between the girders, below the deck and above the counterweight with the leaf in the open position.

The trunnion girder design with two self-aligning bearings is very simple to install and align once at the bridge site. Since two points define a line, two self-aligning bearings are automatically collinear. The typical bascule with two simply supported trunnions has four cylindrical trunnion bearings. Not only must the bearings be collinear but each bearing must be aligned to be parallel to the centerline of the four bearings.

The trunnion girder is an assembly of two trunnion shafts and hubs, two outboard tubes and diaphragms, and a center tube. All of these parts fit together with interference (FN) or locational clearance (LC) fits in order to keep the ends of the trunnion shafts collinear and parallel to each other with zero camber under no load. The entire leaf structural steel was shop assembled. The bascule girders were shipped to the bridge site with the trunnions, hubs, outboard tube girders and the diaphragms as two assemblies. There is no alignment error or adjustment possible during the assembly at the bridge site. The trunnion girder is also stiff enough to prevent excessive angular deflection under dead load. The deflection needs to be minimized so that the coupling can accommodate the variation in angular deflection as the leaf rotates between the closed and open positions. The trunnion girder is not cambered to accommodate dead load deflection because the camber would cause more horizontal misalignment as the deflection decreases as the leaf opens. The vertical misalignment would also vary more as the un-cambered horizontal axis of the trunnion girder is rotated towards the vertical direction.

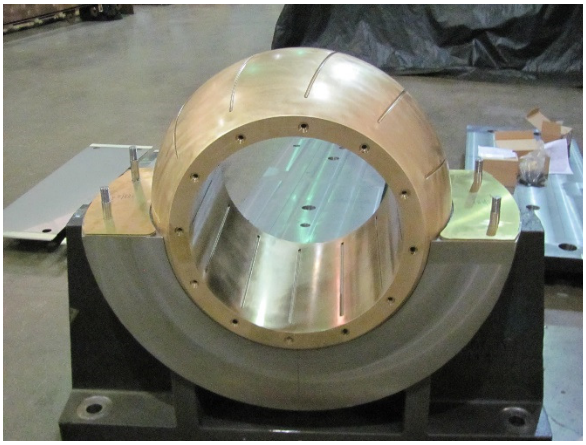


Figure 12: Spherical Trunnion Bearing with bearing cap removed. Grease grooves are visible inside and outside of the bushing.

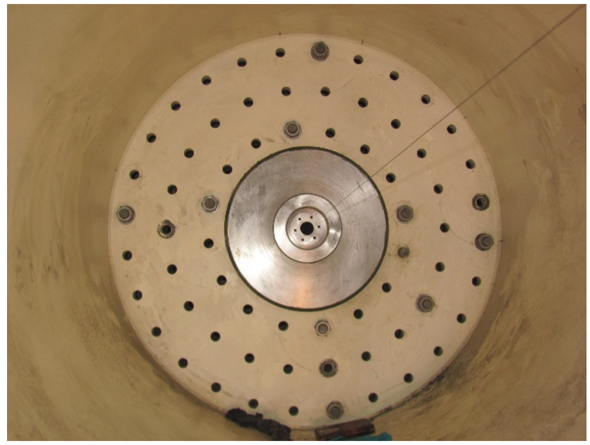


Figure 13: Diaphragm at inboard end of Trunnion Shaft inside Trunnion Girder during shop assembly. Piano wire is strung through trunnions.

Span Drive Machinery

The span drive machinery consists of two separate machineries, North and South, each connected to the outboard ends of the trunnion shafts. Each machinery is not otherwise connected to the other. Each machinery has two 15 HP electric motors, one primary and one secondary. Only one of the two motors in each machinery is energized during span operation but the non-energized motor also rotates. Therefore 30 HP is used to operate the leaf.

Figure 14: Span Drive Machinery Secondary and primary reducers connected with gear couplings during shop testing.

Four brakes are used for the span drive machinery, two in each machinery. All brakes are located on the primary reducer input shaft extensions which rotate at the motor speed of 1750 RPM.

The quadruple reduction parallel shaft primary reducers have a ratio of 256:1. The two stage secondary planetary reducers have a ratio of 33.9:1. The total machinery ratio of 8700:1, from the motor shaft to the trunnion provides a leaf operating speed of 1.2 degrees per second. Including acceleration, deceleration and creep speed operation the leaf can be opened or closed 75 degrees in 90 seconds.

The planetary gearboxes are completely filled with oil to completely submerge all gear meshes. There is an expansion tank instead of a breather.

The output shafts of each of the 2, two stage planetary reducers are connected to the trunnion shafts with large double engagement gear couplings. The output shafts and couplings only rotate 75 degrees. The torque to rotate the leaf transmitted by the lowest speed gears is shared between 6 gear meshes inside the planetary reducers rather than two pinions and racks in the typical bascule leaf. The use of harder and stronger materials, triple the number of gear meshes and better alignment with enclosed gearing, make the compact planetary gear reducer a viable alternative to rack and pinion drives for bascule spans.

Gear Reducer and MachineryTesting

The two primary, two secondary and two tail lock gear reducers were shop tested with a 4 hour no load test and a 1 hour load test. Additionally there was a two hour run test of each machinery assembly. Except for the secondary reducers, the no-load tests were performed at Overton Chicago Gear. The tests of each machinery assembly were performed at G&G Steel in Russellville, AL.

Figure 15: Tail Lock gear reducer testing with output shafts coupled together.

Each no-load test was conducted by driving the input shaft at full speed with an electric motor controlled with a variable frequency drive. Temperatures of shafts near bearings, bearing covers and oil were measured and recorded.

Figure 16: Planetary gear reducers ready for shipment after testing.

The gear reducer load tests for all reducers and the no load tests for the secondary reducers were performed at Clark Testing in Buchanan, MI. There are two primary, two secondary and two tail lock reducers. The tail lock and secondary reducers were tested in pairs. The lowest speed or output shafts of the pair of reducers being tested were coupled together. The input shaft of one of the reducers was driven with an electric motor or an electric motor with a reduction gearbox. The input shaft of the other reducer was connected to a brake, or to a brake with a speed increaser gearbox. Torque was measured at the input shaft near the motor, output shaft between the reducers (tail lock only), and at the input shaft near the brake. The two primary reducers were tested individually by driving the input and resisting rotation at the output with a brake and speed increaser gearbox.

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