Water Street over Eel Pond Channel

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Description

The existing bridge carried Water Street over Eel Pond Channel. Eel pond Channel is the inlet from Great Harbor and Vineyard Sound to Eel Pond. Water Street has two 12 foot lanes for highway traffic in both directions and two 8 foot sidewalks for pedestrian traffic.

The existing bridge consisted of a single leaf bascule span, a counterweight abutment, a rest abutment and approach slabs on fill. The single leaf spans the inlet to Eel Pond. The bascule span was a single leaf Strauss Style with an articulated under deck counterweight. The open grid floor was supported by stringers supported by floor beams framed into two bascule girders. Curved racks on the underside of the bascule girders enable the leaf to be moved by pinions in mesh with the racks. The prime mover was a hydraulic motor located under the leaf. A hydraulically released disc brake was collocated with the motor. A hydraulic pump and electric motor were located is a small wooden shed above grade next to the control house. All speed reduction between the pinions and hydraulic motor was accomplished with open gears located under the leaf and between the bascule girders.

There were four trunnion bearings located inboard and outboard of each bascule girder. There were two counterweight trunnions inboard of the bascule girders at the top of the counterweight. The trunnion bearings were supported on the top of columns. There were two counterweight links connecting the bottom of the counterweight to the inboard towers, stabilizing the counterweight and completing the parallelogram. The bearings of the links as well as the counterweight trunnions were difficult to access.

Existing conditions

The steel superstructure was deteriorated due to corrosion and had been rehabilitated in the past. The machinery was operational but the gear teeth were worn and many components especially fasteners had significant corrosion. There was significant corrosion to trunnion columns and anchor bolts. There were no cracks in the pier or footing.

Design goals

The major design goals included:

- Rehabilitate the bridge to a condition that would provide at least a 30 year life with minimal maintenance.

- Provide roadway and sidewalk cross sections to match the existing.
- Improve the load rating to HS-20 loading.
- Consider an enclosed deck to reduce noise and corrosion and improve safety.
- Minimize disruption to highway, pedestrian and marine traffic during construction. Maintain pedestrian traffic and to all businesses near the project at all times. Avoid any construction activities that would impact the various types of traffic during the summer months.
- Minimize the effects to the bridge during a flood event.
- Maintain the existing appearance.

Minimize the construction cost consistent with the other project goals
Minimize detrimental effects to the Environment.
Maintain the navigation channel.
In order to achieve these goals simultaneously, considering any other bridge type other than a single leaf bascule with an under deck counterweight was impractical. Further the leaf must be located on the west side of the channel. A general design scheme to retain the existing footing and replace the remainder of the bridge was investigated. The alternative would satisfy many of the goals and not adversely affect the other goals not directly satisfied. The new leaf would be heavier with the higher live loading, concrete filled deck. Additional counterweight moment compared to the existing would be required to balance these features. A framing system using two bascule girders, five floor beams, five stringers and two cantilever sidewalks was suitable.
Eliminating the open deck would reduce the traffic noise, improve skid resistance enhancing safety and improving ridability for motorcycles and bicycles. The structural steel below the deck would not be subject to water runoff contaminated with salt or other corrosive chemicals. The decks studied included a lightweight concrete deck, a filled grid deck and an exodermic deck. The filled grid deck was ultimately selected.
The vertical clearance of the navigation channel was less than five feet. All machinery components will be in close proximity to the water with an under deck counterweight style bridge if the machinery were located below and between the bascule girders. The hydraulic motor and brake mitigated the risk of submerging the electric motor on the existing bridge but the open gearing, shafts and bearings would likely be submerged during a flood event. During such an event the lubricant on the gears and bearings would be contaminated with the flood water and some lubricant would be carried away by the water.
In order to mitigate the risk of damage during a flood state the mechanical and especially the electrical components would need to be located as high as practical with respect to mean high water. It would be best to enclose the gearing to the greatest extent possible.
Construction schedule
The area is very busy due to tourist activity during the summer months. The most appealing situation during the summer months of June July August and September would be to have all traffic maintained at full capacity. The construction was required to take place beginning in October and ending in may.

No demolition restricting highway and pedestrian was allowed to begin before October. The new bridge was required to be installed and open to traffic by Memorial day. It was not merely enough to decree this in the contract documents; the design must be thought out and planned so that the construction schedule could be met.
During the construction phase, the existing bridge would be completely closed to highway and pedestrian traffic.
There was no room at the site for a temporary bridge immediately adjacent to the existing bridge. Highway traffic would have to be detoured around Eel Pond during construction. There is significant demand year round for pedestrian traffic crossing the Eel Pond Channel. Pedestrian traffic was maintained with a movable pedestrian bridge. A location next to the bridge was suitable for a pedestrian bridge. The pedestrian bridge would need to be movable in order not to obstruct the navigation channel. The pedestrian bridge was required by the contract in terms of a performance specification. The pedestrian bridge was designed by the contractor and was of the retractile type. The movable span retracted horizontally from across the channel to one side of the channel.

Design challenges

The primary design challenges involved designing a heavier leaf that would fit within the geometric constraints of the roadway and footing elevations and well as the counterweight pit. The leaf must be able to open to 75 degrees to sufficiently clear the navigation channel.
Strauss style under deck counterweight bascules are generally capable of high angles of opening because the main and counterweight trunnion bearings are located as high as possible. The advantage of an articulated counterweight is that all of the mass of the counter weight is applied to the location of the trunnion bearing. The counterweights are generally taller than they are wide creating a relatively large volume. Due to the high locations of the trunnions the leaf can open to a large angle of opening before the counterweight trunnions become too close to the trunnion columns to allow further opening.
Since the Strauss style bascule is rarely duplicated today it was prudent to study alternatives that might provide better solutions to the design challenges.

Trunnion and Counterweight Alternatives

The major factors considered in selecting the trunnion and counterweight configuration included constructability, normal maintenance effort, rigidity, long-term performance and available space on the existing footing. A new bascule pier if required would not result in significantly more space. It would be necessary to lengthen the pier in the direction away from the channel as compared with the present dimensions. The existing footing would have to be removed and replaced with a new footing. Enlarging the pier more than 3 feet in the direction away from the channel would interfere with existing utilities further complicating the project.

- Alternative B-1: A rolling lift bascule is a very common solution where it is necessary to fit the smallest bridge to fit into a tight space. It was considered here and eliminated from further consideration for several reasons. The movement of the dead load reaction on the bascule pier. As the leaf rolls from the closed to the open position and back the weight of the leaf moves in relation to the pier resulting in loads on the pier which it was not designed for. The exposed lubricated tread and track surfaces can be a source of performance difficulties and maintenance. The tread and track surfaces would likely be at or below mean high water. During a flood condition there would be cross contamination between the lubricant on the track surfaces and the saline flood water that flows into the pond and ebbs to the sea.

- Alternative B-2: Replacing the existing Strauss style bascule in kind with similar dimensions would fit into the tight space as long as the counterweight size or density could be increased. This alternative would include the articulated counterweight, similar to the existing configuration. The trunnions would be simply supported on interior and exterior columns at each bascule girder. The inherent problems of the difficult to access main and counterweight trunnion bearings, leaf flexibility would continue to be a disadvantage.

- Alternative B-3: A simple trunnion bascule with a fixed counterweight. This is the most commonly constructed bascule span today. Trunnions are simply supported on both interior and exterior columns similar to the existing bridge. This option was eliminated because:

  The interior columns tend to limit the angle of opening, and limit the size and capacity of the connections between the girders and the counterweight. This is often mitigated by moving the trunnion away from the channel, and lengthening the leaf both ahead and behind the trunnion. Based on preliminary geometric and static analyses, this arrangement would require a longer counterweight arm and consequently a longer, deeper pit. The geometric constraints of the Eel Pond Bridge limit the length and depth of the pit, unless the entire pier is replaced and the sewer lines relocated.

For this reason a bascule span configuration with a fixed counterweight and with interior trunnion columns was not considered further.

- Alternative B-4: A Trunnion Girder Bascule. This structure has no interior trunnion columns and therefore is capable of large angles of opening. Two basic sub-types exist: a rotating trunnion girder and a non-rotating trunnion girder.

  A rotating trunnion girder is a transverse girder located at the center of rotation that rigidly connects the bascule girders. Cantilever shafts protrude from the webs of the bascule girders and are braced by a moment connection to the trunnion girder. The trunnion shafts rest in cylindrical or spherical bearings mounted on top of the trunnion columns. The dead load on the trunnion girder is constant but the direction of load and girder deflection varies as the span opens. This could cause misalignment between sleeve type bearings and therefore spherical trunnion bearings were recommended. A recent example of this type of bridge was constructed in Portland, Maine. It is a fairly large double leaf bascule and has spherical trunnion bearings and a rack and pinion drive. The rack is mounted to the bottom of the bascule girder. Other examples have been constructed recently in Florida.

The main disadvantages of the rotating trunnion girder are excessive trunnion girder deflection in the raised position and eccentric loading of the trunnion bearings due to varying deflection of the trunnion girder. These disadvantages can be mitigated by using a circular cross-section for the trunnion girder and mounting the trunnion girder in spherical bearings. A circular girder was selected to provide a cross section with a constant moment of inertia in all directions. The rigidity of the leaf varies in different directions with respect to gravity. The trunnion shafts could be adjusted in the field under dead load to bearings could be cambered uniform.

A non-rotating trunnion girder has a non-rotating shaft protruding from each side of the girder. The girder is simply supported on two outboard trunnion columns. The trunnion shafts pass through bearings mounted in the web of each bascule girder. The bascule girders and leaf rotate around the fixed trunnion girder and shafts. The dead load on the trunnion girder has a constant direction and magnitude. The deflection of the girder is constant and therefore the trunnion bearings can be installed parallel to each other. There are no recently constructed examples of non-rotating trunnion girder bascules; although there are many still in service that were built in the 1920's, 30's and 40's. The non-rotating trunnion girder acts a support for the deck over counterweight and the span drive machinery. These are advantages for relatively large leaves but not for the small size of the leaf required here. Therefore the study of the non-rotating trunnion girder was dropped from further consideration in favor of the rotating trunnion girder type.

Selection of Trunnion and Counterweight Alternative

The major factors considered in comparing the rotating trunnion girder and the Strauss style bascule were constructability, normal maintenance effort and long-term performance. Both had been studied geometrically and would fit in the available space on the existing footing and could achieve the required angle of opening. The rotating trunnion girder concept was ultimately selected over the Strauss articulated counterweight style. The rotating trunnion girder bascule has the following advantages:

- It has no interior trunnion columns and therefore is capable of large angles of opening, limited only by the counterweight contacting the channel pier wall. With the new lower elevation projected for the trunnions, the entire leaf will be behind the fender at an angle of 80 degrees. The leaf will be able to open to 80 degrees with this configuration.
- The lack of interior trunnion columns increases the room available for the counterweight compared to the other types of bascules. The room is necessary because the weight of the span will be increased as compared to the existing span due to the proposed concrete deck.

- The use of spherical trunnion bearings and machinery directly driving the trunnion would mitigate the effects of the anticipated deflection of the trunnion girder. The deflection of the trunnion girder would be minimized by a deep section with a nearly constant moment of inertia at all angles around the longitudinal axis. A circular or nearly circular cross section provides the same moment of inertia at any angle of opening.

The rotating trunnion girder consists of long tube, two diaphragms, two hubs, two shaft, and two connectors. See figure 1 and figure 2.

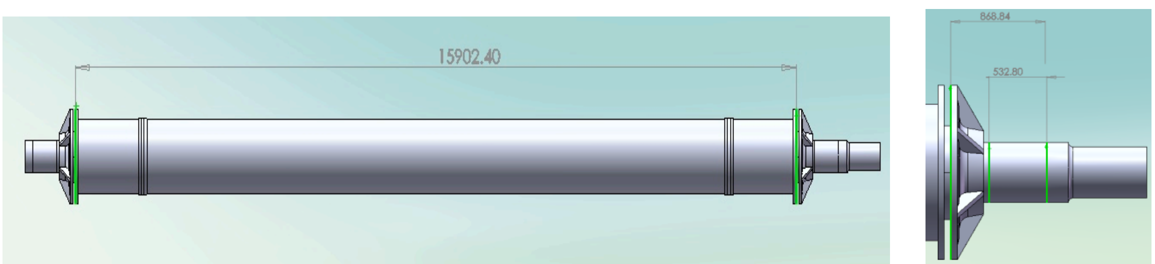

Figure 1: Trunnion Girder

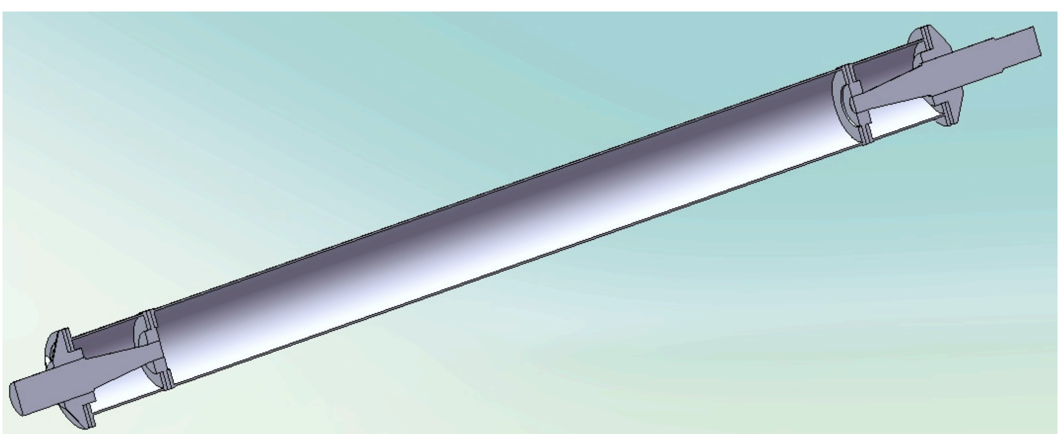
Figure 2: Trunnion Girder Section

Constructability

Assembling the Strauss style leaf on site is systematic sequential stacking from a structural point of view. Mechanically all four trunnion bearings must be in line and aligned with the trunnion shaft axes if cylindrical bearings are used. The two counterweight trunnion bearings can be aligned with each other but must also be the same distance from and elevation with respect to the main trunnions. Also both links must have the same geometric relationship with each other.
This alternative lends itself to span drive machinery located below the deck between the bascule girders.

The rotating trunnion girder concept is optimized for constructability at the project site. All components fit together using cylindrical fits and tight fitting bolts. The assembly in the field will match the assembly in the shop. It is nearly impossible to assemble the trunnion girder with the bascule girders in a misaligned condition. Structural tolerances prevail for the remainder of the leaf.

The rotating trunnion girder type requires temporarily supporting of the trunnion girder between the bascule girders while the bascule girders are erected and connected to the trunnion girder. The advantage is in the bearing alignment, only two trunnion bearings to align. All critical alignment points are at the two trunnion bearings and along the trunnion girder.

Since spherical bearings should be used to absorb any dynamic misalignment, small installation errors are tolerable. The installation errors can result from the trunnion shafts not being parallel to each other, or from the bearing bases not being exactly aligned with the trunnion shaft. There are also no additional counterweight trunnion bearings or links to align. The span drive machinery can also be installed between or outboard of the bascule girders.

Maintenance

- The Strauss style alternative would have four trunnion bearings, two counterweight trunnion bearings and four link bearings. All bearings except the two outboard trunnion bearings are difficult to access, and maintenance is commonly neglected.

- The rotating trunnion girder has only two trunnion bearings. They are located outboard of the girders and therefore the can be more readily accessed for maintenance. There are no counterweight trunnion bearings or links that require maintenance.

Long term performance

The counterweight links and counterweight trunnions have been a source of problems on these bridges

- The articulated counterweight configuration does not provide a rigid connection between the girders. The girders can move independently of each other to a certain degree, twisting the deck.
- The counterweight trunnions and links that are poorly maintained may require replacement.
- The excessive wear associated with cantilever trunnion shafts of the rotating trunnion girder can be mitigated by using spherical trunnion bearings and a tubular or box trunnion girder spanning between the bascule girders.

Span Drive Machinery Alternatives

Various mechanical drive systems were considered for this bridge with the goals of reliability, long life and low maintenance. Maintenance requirements can only be reduced not eliminated. The approach adopted for reducing maintenance is to reduce the number of components, enclose the components and improve the access to the components. One method of reducing the maintenance effort would be to minimize exposed lubricated surfaces. For example, use enclosed gearing and eliminate open gears. Open gearing is cleaned and lubricated by hand at monthly intervals. Open gears are also easily contaminated since they are exposed. The three pairs of open gears in the existing system are located a distance apart from each other and are not as easily accessed as one enclosed speed reducer. Changing the oil in an enclosed reducer once a year requires less maintenance effort than the existing open gear system. A hydraulic motor system similar to the existing system adds a hydraulic pump and motor in exchange for a double reduction enclosed speed reducer. We see a small construction cost savings but less long term reliability and greater maintenance requirements.

<u>Electro-mechanical drive with enclosed Parallel Shaft Gear Reduction Drive Rack and Pinion</u>
An electric motor would be connected to the input of a parallel shaft gear reducer. The output shafts of the reducer would have a differential to equalize the torque between the output shafts. The output shafts would be connected to the pinion shafts with gear couplings and floating shafts. There would be two pinions mounted to the trunnion support structure with spherical roller bearings. Each pinion would mesh with a rack mounted to the bottom flange of each girder.

<u>Electro-mechanical drive with Planetary Gear Reduction to Directly Drive the Trunnion</u>
An electric motor would be connected to the input of a planetary or parallel shaft gear reducer. The output shaft of the reducer would be connected to the end of one of the trunnion shafts and directly drive the bridge. All torque multiplication would take place within the gear reducer and therefore it would be relatively large.

Comparison of Span Drive Machinery Alternatives

Electro-mechanical drive with enclosed Parallel Shaft Gear Reduction Driving Rack and Pinion

- This alternative eliminates all open gears except for the rack and pinion. The rack and pinion will still require field alignment during construction as well as lubrication and cleaning during the service life.
- The required size of the largest gear reducer is smaller than with alternative M-2.
- Through hardened gearing can be used throughout the reducers.
- Manual operation would be provided with a hand crank or wheel that could be installed on the opposite drive end of the motor when the need arose.
- The machinery would be located under the leaf similar to the existing where its location would not interfere with the position of the control house.

Electro-mechanical drive with Planetary Gear Reduction to Directly Drive the Trunnion

- This alternative completely eliminates any open gears including the rack and pinion and minimizes the number of components.
- Maintenance recommendations include checking the oil level within the planetary gear reducer monthly, changing the oil and performing a spectroscopic oil analysis annually, and performing a visual inspection of the gears every five years.
- The planetary gear reducer will use some surface hardened gearing.
- Overloading of the gear reducers can be prevented by using a torque limiting coupling between the motor and the reducer.
- Manual operation would be provided with a hand crank or wheel that could be installed on the opposite drive end of the motor when the need arose.
- The machinery would be located next to the trunnion as opposed to under the leaf, where it could be accessed more easily for maintenance.

The leaf is equipped with two motors rated for 15 HP at 1750 RPM. Both motors are connected to opposite ends of the continuous input shaft of the primary reducer with controlled torque couplings... Only one motor is energized at one time to power the leaf. A shoe type thrustor brake is located on both ends of the primary reducer input shaft. The non-energized motor rotates under no load. The motor to be energized is manually selectable by the operator. There is no provision to operate the motors simultaneously. The 15 hp motors are vector duty squirrel cage motors. Flux Vector drives provide automatic speed control of the motors.

The output of the primary reducer is connected to the input of the secondary reducer with a floating shaft and single engagement flexible gear couplings. The secondary reducer is connected to the South trunnion shaft with a double engagement gear coupling. The primary reducer is a triple reduction parallel shaft with a ratio of 148:1. The secondary reducer is a two stage planetary reducer with a ratio of 32:1. The total ratio of the span drive machinery is 4376:1.

The specification referenced for the design was the 1988 AASHTO Standard Specification for Movable Highway Bridges. The 2000 AASHTO Standard Specification for Movable Highway Bridges was selectively used for additional guidance on shaft fatigue, span balance and prime mover sizing. All machinery components were designed to resist at least 150% of the Full Load Motor Torque (FLMT) produced by the 15 hp motor.

Span Locks

Two Span locks were provided in the rest abutment under the sidewalks. The span locks were Earle and the bars engaged receiving sockets in the sidewalk brackets at the toe floor beam.

Traffic Gates

The existing gates were manually operated swing gates The arms were a steel frame around a riveted lattice. They have been historically effective at this site in controlling vehicular traffic, used in conjunction with the traffic signals.

The bridge site is very constrained due to the urban setting. Providing both resistance gates at the bridge, and warning gates further from the span, is not practical because intersecting business driveways right near the bridge would make the warning gates ineffective. Pedestrians would just tend to walk around them as well.

The existing gates were replaced in kind using welding and bolting rather than riveting. The gates were modified and converted to resistance gates by adding austenitic stainless steel wire ropes to the gate arms.

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