Design Build Reconstruction of the Murray Morgan Lift Bridge

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Bridge General Description

The Murray Morgan Bridge crosses the Thea Foss Waterway in Tacoma, Washington. The bridge has a total length of approximately 1760 feet, and is comprised of three distinct sections – the City Approach (or west approach), a multi-span steel girder structure, erected in 1913; the Port Approach, a multi-span prestressed concrete girder structure built in 1954 to replace the original approach structure; and a three span steel through truss (approximately 600 feet long) main water crossing with a 221 foot long Pratt through truss vertical lift span built in 1913.

The Murray Morgan Bridge is one of the last remaining examples of the Waddell and Harrington's (predecessors of Hardesty & Hanover, LLP) original span drive type vertical lift bridge designs. It was placed on the National Register of Historic Places on July 16, 1982.

Due to concerns about advancing corrosion and loss of load capacity, the bridge was completely closed to vehicular traffic in September of 2007 by the Washington State Department of Transportation.

Murray Morgan Bridge

Project Overview

After many years of debate on whether to demolish or rehabilitate the bridge, ownership of the bridge was transferred to the City of Tacoma along with funds for reconstruction. Using the Design Build Delivery Model, the City of Tacoma qualified three construction teams and subsequently issued a Request for Proposal to rehabilitate the structural based on a complex work scope.

Hardesty & Hanover developed a preliminary RFP design package for the purposes of pricing the repairs and grading by the Owner that the level of repairs met the expectations.

In January 2011, the City of Tacoma awarded the design build contract to the PCL Civil Constructors/Hardesty & Hanover Team.

Rehabilitation Scope of Work

The major rehabilitation scope of work items included the following:

City Approach

- Remove and replace existing bridge decks
- Remove the cantilevered sidewalks and sidewalk brackets
- Convert the existing 4 lanes of traffic to 2 lanes of traffic and 2 pedestrian/bicycle lanes
- Install new traffic barriers and pedestrian railings
- Analyze and perform a Phase 1 Seismic Retrofit on the super structure of the City Approach
- Remove and replace deficient rivets on the City Approach
- Install a stormwater collection system and treatment basin
- Install an under deck inspection access catwalk system
- Replace City Approach stairway to Dock Street

Center Truss Spans

- Remove and replace existing bridge decks

- Remove the cantilevered sidewalks and sidewalk brackets
- Convert the existing 4 lanes of traffic to 2 lanes of traffic and 2 pedestrian/bicycle lanes
- Install new traffic barriers and pedestrian railings
- Analyze and perform a Phase 1 Seismic Retrofit on the super structural of the Center Truss Spans
- Remove and replace deficient rivets on the Center Truss Spans
- Install a stormwater collection system and treatment basin
- Install an under deck inspection access catwalk system
- Replace the operating machinery and bridge control systems
- Install a new traffic control system including traffic signals, traffic barriers and warning gates
- Install a new span lock system
- Replace the counterweight sheaves

Port Approach

- Convert the existing 4 lanes of traffic to 2 lanes of traffic and 2 pedestrian/bicycle lanes
- Remove and replace the asphalt overlay and waterproofing membrane on the bridge deck
- Analyze and perform a Phase 1 Seismic Retrofit on the super structure of the Port Approach
- Install a stormwater collection system and treatment basin

Project Funding

The original construction contract dollar amount was $46,870,000 to perform the engineering and complete the construction work. A contingency budget of $2,343,500 (5%) for unforeseen conditions and unanticipated repairs was also included. After project award, the City of Tacoma secured funding in install a City Approach Elevator, thereby eliminating the non-ADA compliant stairway system from Dock Street. The elevator design and construction budget was $3,500,000.

Design Approach to a Design/Build Bridge Rehabilitation

The successful DB Team had to develop a strategy to provide the best value design for a capped budget amount of $47,000,000.

Our methodology to maximize the rehabilitation while keeping within the capped funding is shown in the approach to the following major rehabilitation items:

- We recognized that the repair methodologies for the most severely deteriorated members must account for the likelihood that these members are most vulnerable to future deterioration. Our repair/replacement concepts for these members maximize their bridge legal load rating factors to guard against their vulnerabilities. For example we achieved:

  Truss Bottom Chords RF≥ 4.0

  Truss Bottom Chord Gussets RF≥ 3.5

- **Rehabilitation of Truss Bottom Chords** - We developed an innovative method to strengthen the chords using four (4) 2-1/2" diameter rods that will run the full length of the chords. The rods (ASTM F1554 Gr. 55) have a structural capacity equal to the existing as-built chords. Therefore, they not only will provide additional capacity, the essentially provide full redundancy to the chords. This is a key feature of the design since we are providing redundancy to the fracture critical chords.
- **Rehabilitation of Truss Bottom Chord Gusset Plates** - As part of the truss bottom chord strengthening, we also **repaired all gusset plates** by adding new gussets at each panel point along the bottom chords of the trusses. The existing gussets are 3/8" thick. The new plates will be ½" thick. To facilitate erection and reduce costs, we developed an innovative rivet replacement procedure that utilized eccentric collars with HS bolts that permits gusset replacement without countersunk bolts or jacking.
- **Phase 1 Seismic Retrofit of Truss Spans** – We choses to strengthen deficient truss and tower bracing members rather than replace existing members where feasible to provide the maximum service lives. Innovative details similar to those employed for the truss bottom chords eliminated the need for temporary supports t strengthen these members. We replaced existing roller nest bearings with seismic isolation bearings at Piers 1 and 4. We strengthened the connection of the tower columns to Piers 2 and 3 and reinforced these pier caps.
- Completely **new bridge decks** were constructed for the City Approach and Truss Spans. Reinforced concrete decks were used except at the lift span where an Exodermic deck was used.
- **Stringers were replaced** on the City Approach and the Truss Spans.

- **City Approach Bent Column Bases -** An innovative underpinning detail was utilized to repair the deteriorated column bases. The repair consists of twin partial height steel columns will be provided and encased with a new concrete pedestal.
- **ATC No. 1** – Operating Machinery Drive Motor Replacement- Our design concept, as presented in Alternative Technical Concept No. 1, is to provide a speed reducer with a double extended input shaft. Normally, a single drive motor connected to one side of the input shaft will provide the power for bridge operations. This frees up the opposite side of the input shaft for the installation of a reduced power emergency drive system.
- **ATC No. 2** – Counterweight Sheave Replacement - Our team has developed a unique concept design to incorporate spherical roller bearings into the counterweight sheave assemblies minimizing project costs and structural modifications.

Structural Element Load Rating Factor

A minimum rating factor of 1.25 was specified in the RFP for all primary members.

We have developed a member repair/replacement plan that will elevate the rating factors for primary load carrying members to a minimum of 1.5 for the City Approach. The following table shows the rating factors achieved:

Members	A
Concrete Encased Steel Column Bases	1.50
Steel Bent Columns	1.50
Steel Bent Riveted Connections	
Steel Girders	1.83
Steel Floorbeams	1.50
Steel Stringers	3.44
Steel Riveted Connections	1.80

We developed a member repair/replacement plan that will elevate the rating factors for primary load carrying members on the truss spans to a minimum of 1.5 for the truss spans.

Members	A	B
Steel Truss Bottom Chord	4.0	
Steel Truss Bottom Chord Gussets	3.50	
Steel Truss Vertical/Diagonal/Top Chord		1.68
Steel Floorbeams	1.50	1.42
Steel Stringers	2.32	
Connections	1.80	1.25

Structural Rehabilitation Highlights

Truss Spans – Lower Chord Strengthening

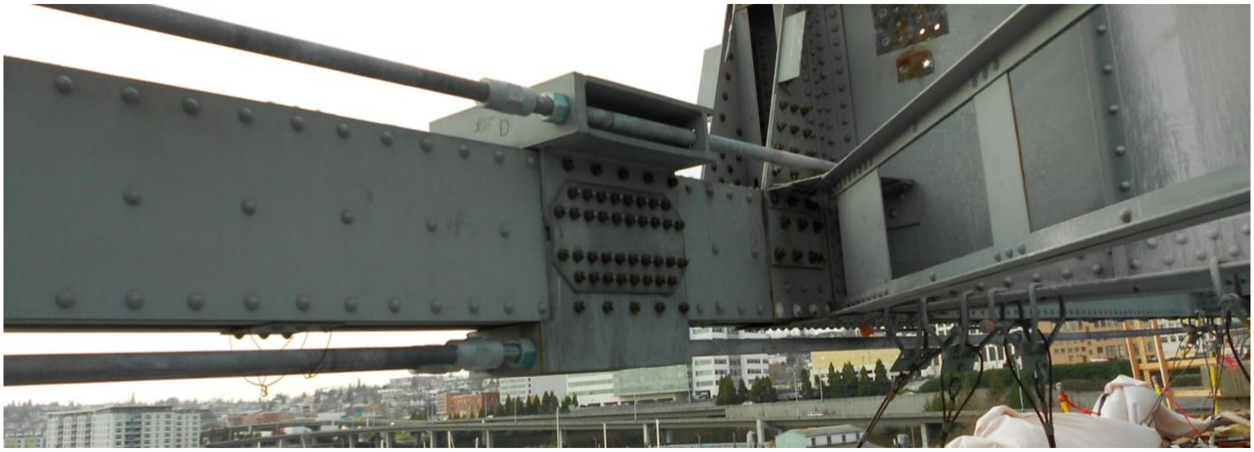
We studied two options to strengthen the heavily deteriorated truss bottom chords:

1. Replacement of Bottom Chords
2. Strengthening Retrofit of Bottom Chords

Replacement of the bottom chords was studied but was found to be not cost effective because of the difficulty of erecting the new chords. The existing construction minimized the number of splices in the chords and large sections were erected in the field. To do this, every panel point of the truss was supported off false-work during the erection phase. This is not possible now.

Since the chord replacement was deemed not feasible, we developed an innovative method to strengthen the chords using four (4) 2-1/2" diameter rods that will run the full length of the chords. The rods (ASTM F1554 Gr. 55) have a structural capacity equal to the existing as-built chords. Therefore, they not only will provide additional capacity, the essentially provide full redundancy to the chords. This is a key feature of the design since we are providing redundancy to the fracture critical chords.

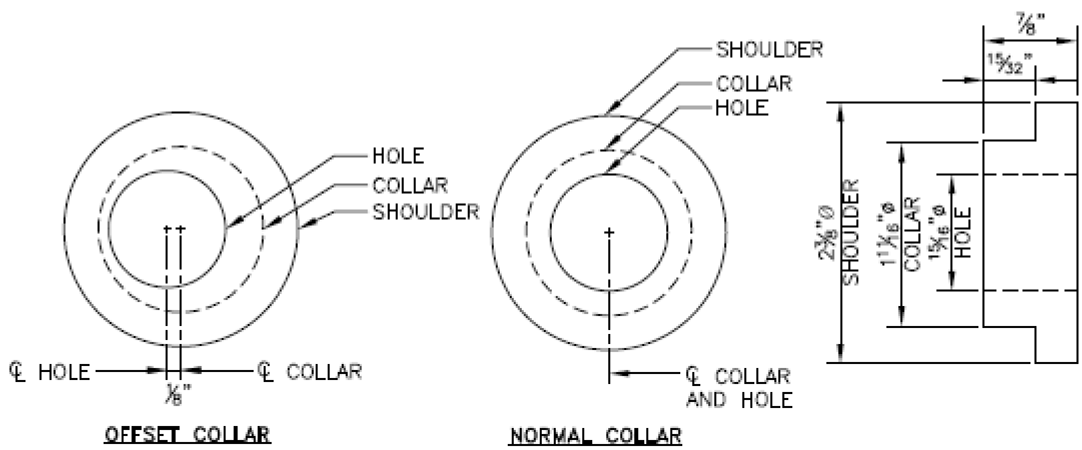
A pre-load was jacked into the chords to eliminate the existing overstress condition in the chords due to section loss. This strengthening retrofit design also repairs the damaged to chords at panel point connections since it provides a fully redundant load path through these connections. Since the strengthening has much more capacity than required to achieve a 1.25 rating factor, we did have to repair the deteriorated areas of the existing chords.



Truss Spans – Gusset Plate Repairs

As part of the truss bottom chord strengthening, we also **repaired all gusset plates** by adding new gussets over existing gussets at each panel point along the bottom chords of the trusses. The existing gussets are 3/8" thick. The new gussets are ½" thick.

To facilitate erection and reduce costs, we developed an innovative rivet replacement procedure that utilized eccentric collars with 7/8" ASTM A490 HS bolts that permits gusset replacement without countersunk bolts or jacking. Collar details are shown below. By having both offset and normal collars, misalignments between existing rivet holes and holes in new gussets could be corrected by selection of the appropriate collar.



COLLAR DETAIL FOR 7/8" DIA. BOLT
(ASTM A572 GRADE 50 STEEL)
SCALE: 1'–0" = 1'–0"

New gussets were fabricated based on existing shop drawings. Not all rivets required replacement since the new bolts have higher capacity than the rivets. Selected rivets had their heads removed and their shanks were left in place. The new gussets sandwiched the shanks so they cannot fall out. At locations where rivets were to be replaced, new temporary bolts were installed first. The new gussets were then placed over the existing gussets. The enlarged holes for the collars fit over the temporary bolts. The temporary bolts were replaced with the collar and new bolts several at a time so no temporary supports were required.

Lift Span – Exodermic Roadway Deck

An Exodermic Deck was utilized to replace the deck on the lift span to minimize weight on the span. The Exodermic deck is galvanized for protection and comes with SS form pans that facilitate placement of concrete. The deck is attached to stringers with composite action with shear studs on the stringers and poured full depth concrete haunches. This eliminates tedious details required with filled grating decks historically used for this application. A half depth fill of concrete with an reinforced overfill is utilized for the areas not directly over stringers.

City Approach – Column Base Repairs

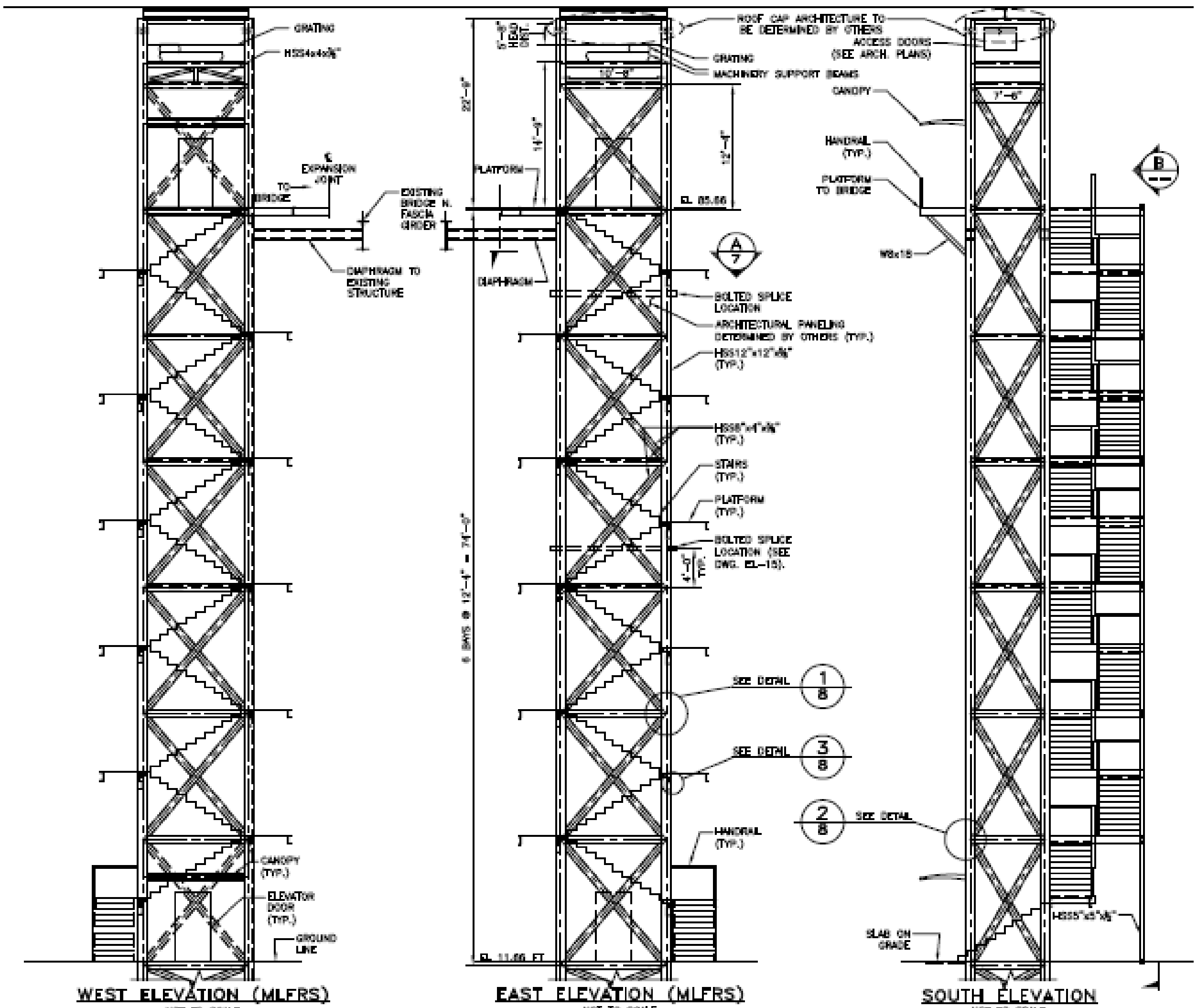
A modified underpinning detail was utilized to repair the deteriorated column bases. The repair consists of twin partial height steel columns will be provided and encased with a new concrete pedestal. Repairing the column bases where they were deteriorated would have been difficult because the steel sections are filled with concrete where the deterioration is located.

The tops of the columns were also be strengthened (at Bents 4, 7 & 9) to repair section loss due to corrosion. All bents will receive repairs to the existing bracing as well as additional new cross and longitudinal bracing in order to provide the necessary upgrades to the bents to allow for all legal traffic to use the bridge crossing with no load restrictions and to provide seismic load capacity.

City Approach – Elevator Design

The existing stairs from Dock Street to the top of bridge at the City Approach provide access for pedestrians who live along the waterway. The provide better access, The City of Tacoma decided to replace the stairs with a new structure that contains both and elevator and stairs.

A new 97-ft high structure was designed to contain the elevator and external stairs. The foundation utilizes micro piles and a concrete footing. The structure is composed of welded HSS sections. Curtain walls enclose the elevator and the stairs are exposed.



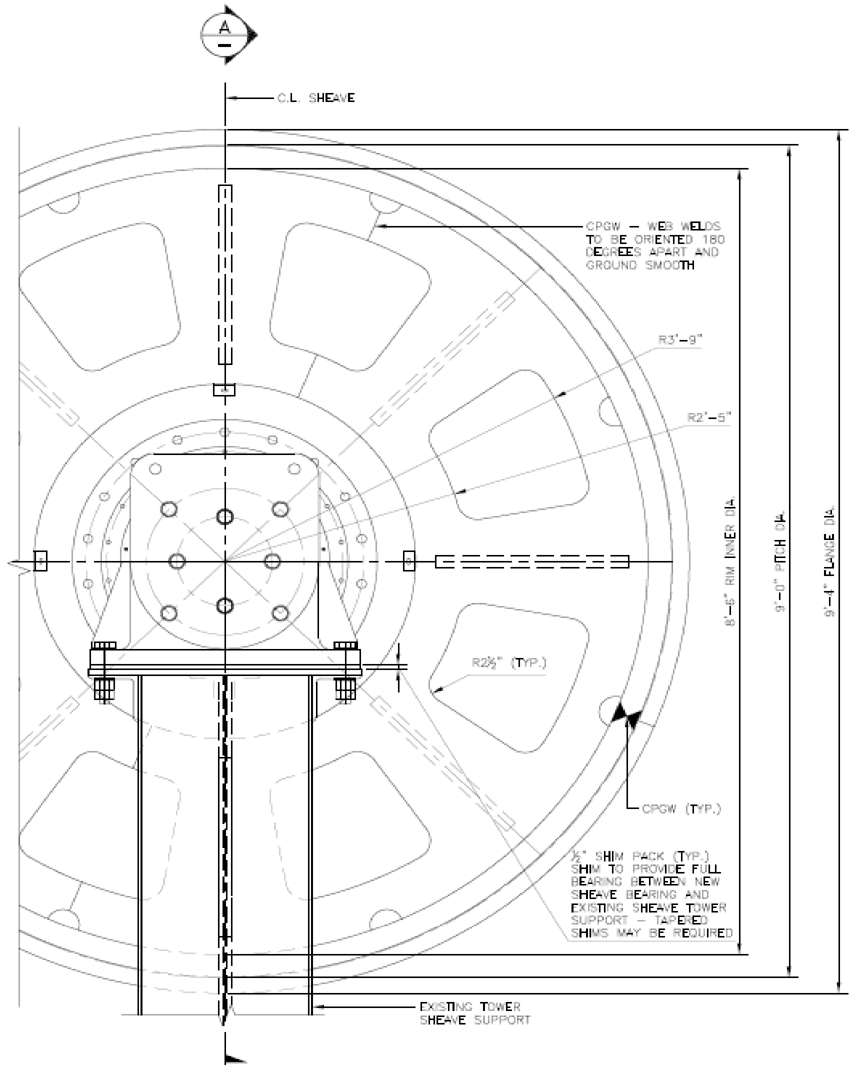
Mechanical and Electrical Rehabilitation Highlights

Counterweight Sheave Replacement

Prior to the City of Tacoma taking ownership of the bridge, the Washington State Department of Transportation replaced the lift span's counterweight ropes and equalizer devices. However, the replacement of the original counterweight sheave and bearing assemblies was left to be part of the major rehabilitation.

The RFP called for a design utilizing counterweight sheaves simply supported by spherical roller pillow block bearings. Utilizing the procedure for an Alternate Technical Concept (ATC), Hardesty & Hanover designed a counterweight sheave system utilizing a fixed trunnion shaft and a sheave with internal spherical roller bearings that rotated around the fix shaft (see Figure M-1).

Extensive collaboration with the Timken Bearing Company took place during the design phase to make the bearing selection and develop a seal system.



COUNTERWEIGHT SHEAVE ASSEMBLY ELEVATION
(4) REQUIRED
SCALE: 1½" = 1'-0"

Advantages of this system include:

- Significant reduction in the total system friction thereby reducing the overall machinery size and input power requirements
- Fixed trunnion shaft eliminates fatigue issues associated with highly loaded trunnion shafts
- Each trunnion shaft/sheave/bearing assembly was fully shop assembled reducing risks associated with field assembly (pillow block alignment, contamination, etc.)
- Fixed end bearing design simplifies in-field installation

Operating Machinery Modernization

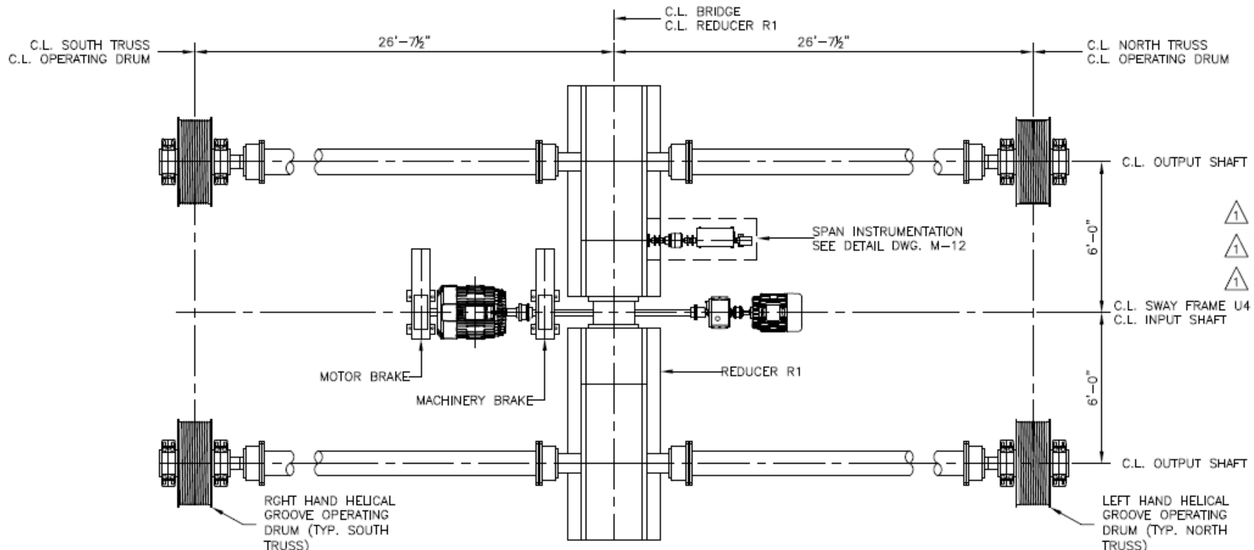
The original lift span operating machinery was a Harrington style span drive machinery system. It is a simple tried and true system utilizing an open gear frame with four output shafts, each driving an operating drum. Each operating drum houses one uphaul and one downhaul rope.

Located above the lift span truss, input power from two 75 HP gear motors rotate the four operating drums thereby raising or lowing the lift span.

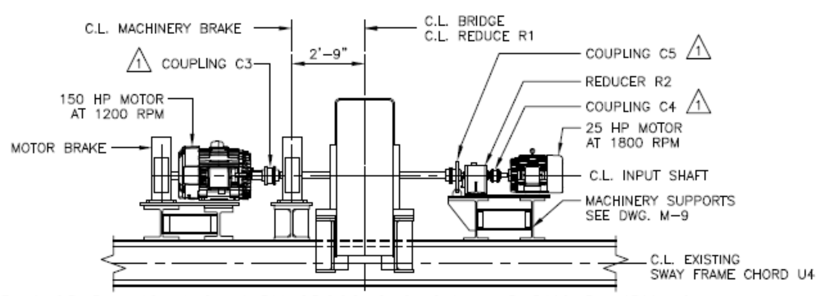
The RFP documents called for replacement of the complete operating machinery system including the open gear frame. An enclosed gear system was specified utilizing two 75 HP drive motors as well as the ability to operate the system via an auxiliary drive motor powered by a City of Tacoma owned portable generator.

Under a second ATC, Hardesty & Hanover proposed a span drive machinery system with the following features:

- Utilize a large, 3 piece enclosed gear reducer, combining the gear ratios of the original gear motors and the open gear frame into one unit
- Utilize a single double extended reducer input shaft, one for the main single electric motor drive and one for the auxiliary drive motor
- Main drive power to be a 150 HP @ 1200 RPM electric motor with flux vector drive
- Auxiliary drive to be a 25 HP @1800 RPM electric motor with a cutout coupling and auxiliary gear reduction



SPAN OPERATING MACHINERY PLAN VIEW
SCALE: 3/8" = 1'–0"



SPAN OPERATING MACHINERY CROSS SECTION AT REDUCER INPUT SHAFT
SCALE: 3/8" = 1'–0"

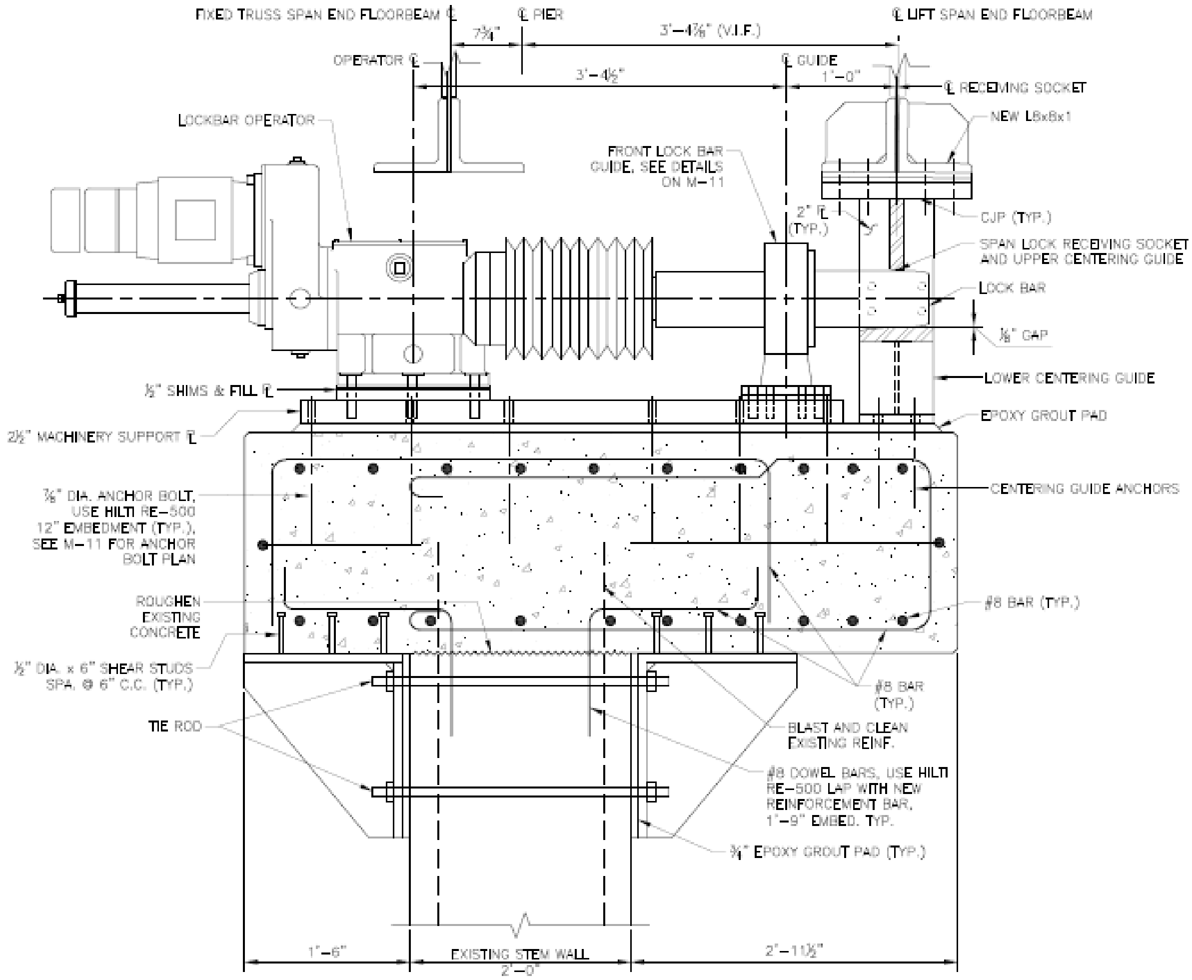
Addition of Span Lock and Centering Device System

The nearly 100 year old structure was never fitted with any sort of span locks or centering devices on the lift span proper. The requirements of the RFP called for installation of a span lock and centering devise on each side of the lift span.

Working within the existing available space constraints was difficult. A concept was developed combining both a span lock and a centering guide into a single compact system. See Figure M-XX below.

Earle Gear Lock Bar Operators were selected for their compact space saving design.

The span lock receiver/centering guide is design to yield under a significant seismic event.



Vector Drive System with Single Main Motor

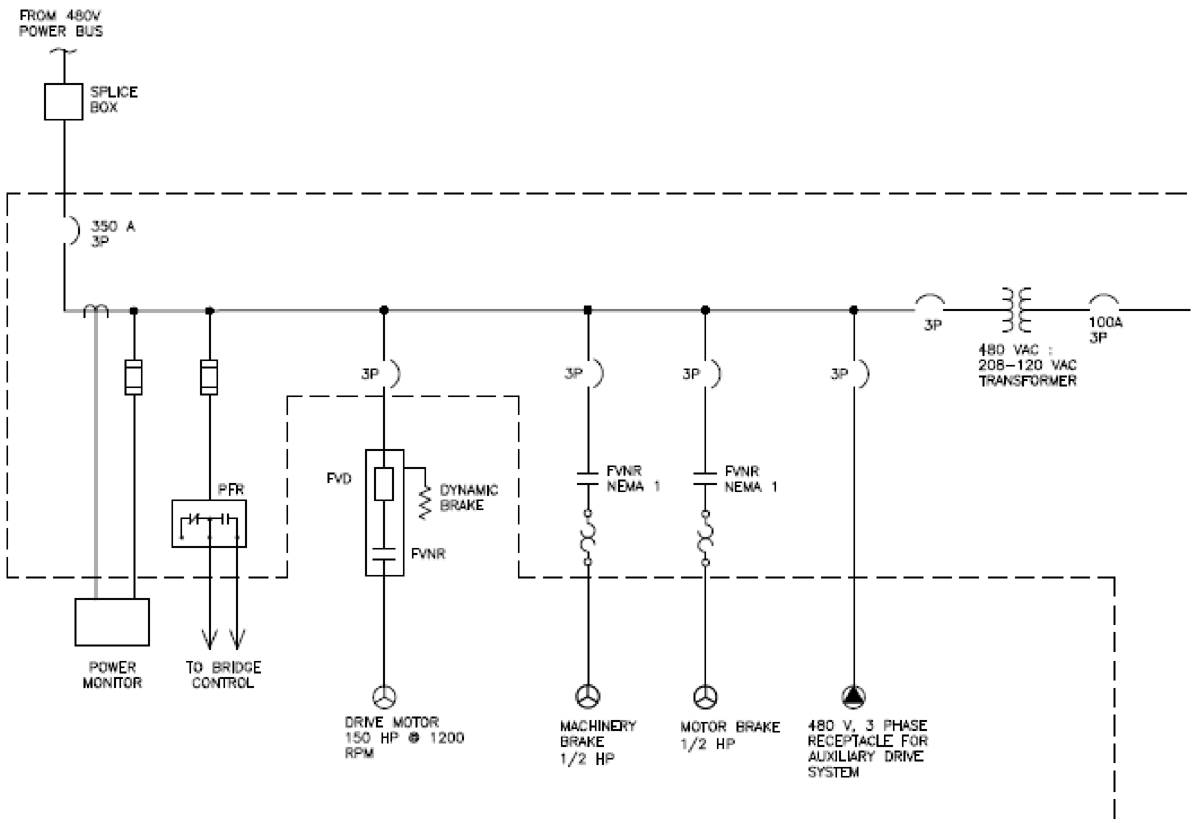
The Murray Morgan Bridge design had several constraints in selecting the drive to operate the main motor, the two primary constraints were space and cost.

Hardesty & Hanover investigated the option of installing a hydraulic bridge operating machinery system. The City of Tacoma desired a motor drive system with a configuration similar to their other movable bascule bridge (the Hylebos Bridge). We then investigated a standard configuration of two separate drive-motor systems, each drive controlling a single fully sized motor to operate the lift span independently. This option would be problematic due to the size restraints of the existing machinery room.

It was concluded that the simplest and most reliable drive system was a single drive that controls a single motor for span operation. This prevents load sharing issues and simplifies the operation of the motor and drive. A four quadrant - flux vector drive and variable speed drive was sized and selected.

We designed a back-up squirrel cage electric motor with an auxiliary speed reducer connecting to the opposite end of the drive machinery's main input shaft. There is a manually engaged disconnect coupling to connect the auxiliary motor and a simple across the line starter to operate the motor.

This configuration provides a fully sized main drive and a lower speed auxiliary drive, meeting the technical requirements of the specifications.



Lift Span – Partial One Line Diagram

Wireless Traffic Control Communication System

The Murray Morgan bridge technical specifications required many existing architectural features remain for historical significance. The existing vertical 480VAC, 3 wire, exposed wire power bus and a parallel 240/120VAC, two wire, exposed wire power bus was one such feature. The existing vertical lift bridge used constant pressure on the wires during bridge operation to keep the motors powered, a system very similar to a trolley wire system. Of course the replacement had to be safer and meet current code requirements.

The new power rail system design is a standard crane power rail with dual shoes to ensure continuous contact with the rail that is orientated in a vertical position. The power rails are enclosed, providing a 'finger safe' system.

Under another "Alternate Technical Concept", the design team proposed to provide a single 480VAC, 3 phase power rail and then a transformer at the control house to step down to low voltage (rather than two independent power rail systems). This reduced the quantity of power rails to maintain, reducing the future maintenance and providing better reliability. It improves the reliability of the system, because if the low voltage rail was lost then control power would be lost and the span inoperable. With this option the span can be operated as long as there is power.

This left a situation where we had power to the bridge, but no hard cable connection for the control wiring. Any hard wired droop cable or cable reel connection on a lift bridge would be costly to install and would be a maintenance intensive item. Since we have PLC capabilities, this was a prime opportunity for a wireless application to provide the necessary communication connection between movable span and bridge equipment (traffic signals, gates, barriers and locks) on the fixed City and Port side approach spans.

There were no specific RFP requirements for the connections between the movable span and the fixed span for the control system. However, the RFP required an Allen-Bradley PLC control system and more importantly a true PLC system with all controls through the PLC. Even on PLC controlled bridges there are extensive relay back-up systems that keep computer control minimized. However, this design encouraged a full PLC control system and this was the ideal option for a creative communication solution.

The wireless design provides two transmitting antennae on the movable span, with receivers at the approach span PLC remote I/O panels. This provides parallel communication and minimizes the wiring connections. All the panels were located on the north side of the span, allowing for easy line of site between the antennae. We selected the ProSoft company's 2.4GHz Industrial Hotspot wireless Ethernet broadband antennae system, based upon successful use on similar projects. The system is provided data security, with encryption and integrity checks.

All PLC controls can be transmitted from the movable span to the approach equipment. The only hard wired connections that AASHTO required is for hard wired connections to the bridge machinery equipment, which is located on the movable span. The equipment on the approached have the emergency stop signal transmitted to the equipment via the wireless system with full inter-locking capability.

This creative solution is a single 480V, 3 wire, power rail and a radio communication system. This minimized equipment costs and the maintenance required for the system, while providing a robust and reliable system.