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Machinery/Mechanics

Stillwater Vertical Lift Bridge Rehabilitation

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Abstract

The rehabilitation of the historic Stillwater Vertical Lift Bridge in Stillwater, Minnesota required the complete redesign of the drive machinery for the 140 foot vertical lift two lane highway bridge. See Figure 1. The bridge was designed by Ash, Howard, Needles and Tammen in 1929 and was built in 1931 by the American Bridge Company (see Figure 2). The Stillwater Bridge was added to the National Register of Historic Places in 1989.

Figure 1: Stillwater Lift Bridge

The bridge is owned jointly by the States of Minnesota and Wisconsin and crosses the St. Croix River. Being only one of three "Waddell and Harrington" type span drive vertical lift bridges remaining in operation in the State of Minnesota, and being on the National Register of Historic Places, preservation of the historic aspects of this bridge for the rehabilitation plans was paramount to the project stakeholders. A unique feature of this bridge from a machinery design standpoint is almost all of the machinery is located beneath the deck of the bridge.

The goal of this paper will be to detail the rehabilitation design of the drive machinery. The existing machinery relies on a chain drive to transfer power from the tender's house to an open gear reduction underneath span. It was desired to replace the chain drive and open gearing due to accessibility problems and maintenance concerns. Since the existing tender's house could not be enlarged due to historical reasons, several alternatives were examined. Challenges encountered for this project included fitting new machinery in the very restricted space of the existing tender's house and beneath the deck of the bridge.

Figure 2: Original Bridge Nameplate

The final design consisted of replacement of the chain drive and open gearing with shafting and enclosed reducers. Three right angle reducers were used to transfer power from the electric drive motor located in the tender's house to a central reducer located beneath the deck.

Background Information

Original Design

The original machinery had a prime mover of a 25 HP gasoline engine. This gas engine was mounted in the relatively small tender's house and was directly coupled to a 3:1 reducer. Power was then transmitted from the deck level to the machinery level below the road way stringers by means of a link belt chain and sprocket assembly (see Figure 3). Once below the deck, power was then transmitted by a shaft to an open gear set. This shaft was also attached to a capstan located on the bridge deck for manual operation. The open gear set consisting of two separate pinions and gears could be shifted by a linkage and lever arm assembly from the tender's house permitting high and low speed operations.

Figure 3: Tender's House. Note chain drive location

Operational History

There were various changes to the operating machinery over the years. The original gas engine was replaced in 1980 with a eddy current drive motor. The capstan was removed as a means of auxiliary operation of the span in 1998 and an AC drive motor and enclosed reducer was added. The counterweight ropes were replaced in 1971. All other machinery is believed to be original.

Historical Significance

Stillwater is very proud of its bridge. Many restaurants in the small town of Stillwater have photographs, murals or other artist's renderings of the bridge on their walls. The bridge was added to the National Register of Historic Places in 1989. The bridge is even used for a backdrop in a scene from the movie "Grumpier Old Men".

Inspection Findings

The chain drive that transferred power from the drive unit to the machery below was difficult to access and maintain. It was located between the tender's house and the vehicular guard rail.

The open gearing sets showed considerable wear (Figure 4). The pinion and bull gear for the operating drums had the most pronounced wear. This could be due in part to debris from the roadway having accumulated on the gear set over the years. Additionally the open gearing underneath the bridge was worn.

Figure 4: Operating Drum Pinion. Note severe tooth wear.

The take-up devices for the up-haul rope were found to be frozen in place by corrosion. The down haul rope take-up devices functioned still but were difficult to access on the small pier tops. The counterweight ropes were beginning to show signs of flattening on the outer strands. Similarly, the operating ropes were well worn and in need of replacement.

Ultra-sonic, non-destructive testing was performed on the counterweight sheave trunnion by a sub-contractor. This testing was performed to determine if there were large, easily detectable defects in the shafts that can result from reversing loads. While it is understood that this type of inspection has the possibility of not detecting small flaws, it is useful tool for the detection of large defects. No defects were found from the inspection.

Rehabilitation Design

Constraints

Due to the historical significance of the bridge, the Minnesota State Historical Preservation Office (SHPO) played a large role in evaluating the rehabilitation alternatives. Of paramount importance to the SHPO was maintaining the original appearance of the bridge as much as possible.

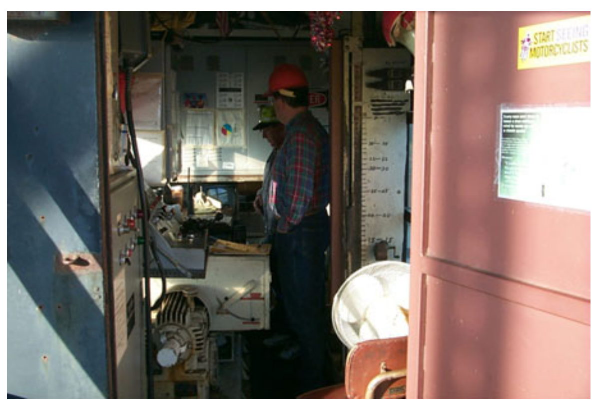

Figure 5: Inside Tender's House. Note limited space.

The current tender's house contains the eddy current motor, control system and the bridge operator. The house measuring approximately 12'-5" by 4'-11" on the interior, did not meet NEC code for clearances around electrical equipment and left little room for the tender and the drive equipment (see Figure 5).

Also the bridge is subject to seasonal flooding. This flooding can rise to the point where the machinery below the deck can be immersed. This made mounting electrical equipment below the deck undesirable.

Another constraint faced in the machinery design for this structure was the limited access to and low clearance of the machinery area beneath the bridge deck (see Figure 6). There exists approximately 3'-0" of clear space between the bottom of the stringers and the top of the machinery grating. The grating could not be lowered in the rehabilitation design because it would interfere with the navigational clearance underneath the movable span when it was closed.

Figure 6: Machinery Area. Note limited space between stringers and grating.

Final Machinery Configuration

An alternative was selected that allowed the original tender's house to remain in its original state from outside appearances. Inside the house would contain the tender, drive motor, motor brake and right angle reducer. An additional house would be built right next to the original tender's house. The new house (electrical house) would contain the electrical panels necessary to operate the new drive system and meet electrical code for cabinet clearances. This alternative was determined by the project stakeholders to have the least impact on the historical aspects of the bridge while providing the rehabilitation required to ensure the bridge would operate well into the future.

The eddy current drive was problematic and unreliable. It will be replaced with a 40 HP DC drive system. This power increase for the drive motor was the result of slightly more conservative design criteria than was in place from the original design. The chain drive was difficult to access and maintain due its location between the guard rail and the house. It will be replaced with a series of right angle reducers. A right angle reducer from the tender's house will transfer torque from the horizontally mounted drive motor vertically to another right angle reducer below. The layout of the machinery in the tender's house can be seen in Figure 7.

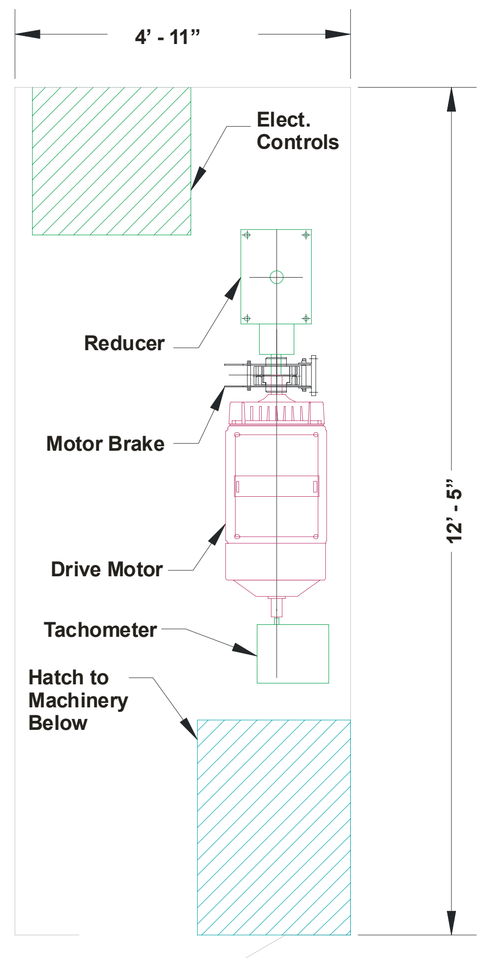

Figure 7: New Tender's House Layout

Once below the tender's house, a second right angle reducer will transfer the torque from the vertical output shaft of the reducer above back horizontally. A detailed layout of the machinery below the bridge deck can be seen in Figure 8. A third right angle reducer will divert the torque into the main reducer underneath the bridge deck.

Since the auxiliary drive and reducer were relatively new and in good condition, it was decided to reuse them if possible. The auxiliary drive and reducer will be attached to a clutch mechanism to allow for remote engagement. The auxiliary reducer will be coupled to the main reducer through an auxiliary input shaft.

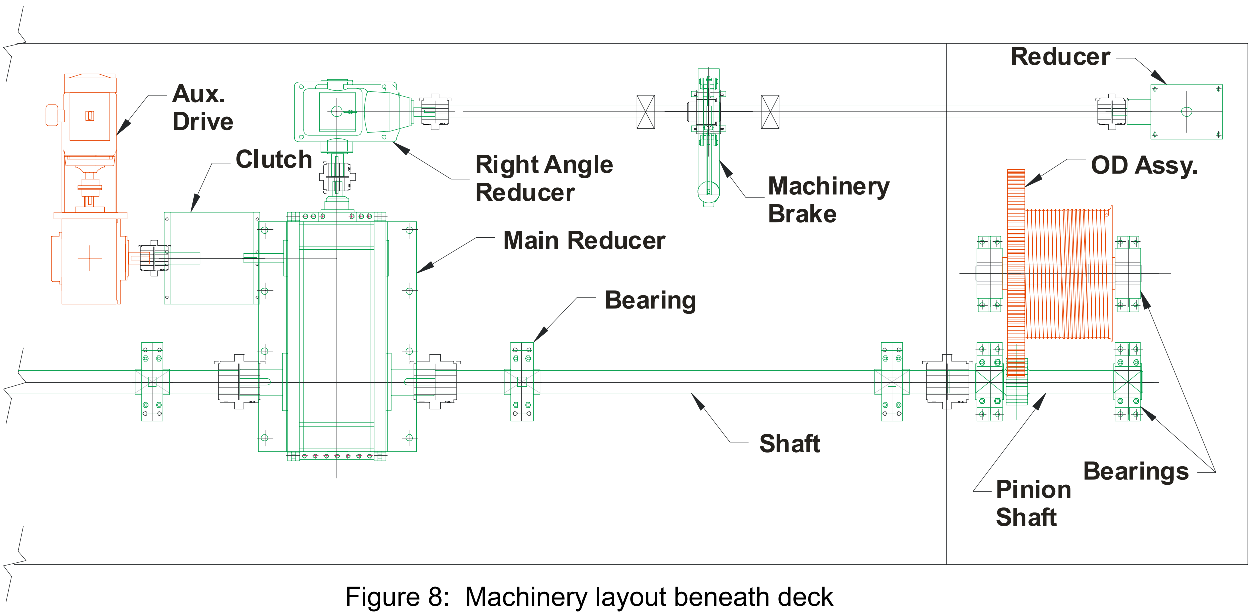

Figure 8: Machinery layout beneath deck

The main reducer had to provide the necessary reduction for the main drive systems, the necessary reduction for the existing auxiliary drive system and also fit limited space of the machinery area. An Earle Gear 8TR (Special) gear box was selected for the task. The reducer must have a saddle type mount in order for it to project above the bottom chord of the roadway stringers. This allows the reducer to fit in the small machinery area.

From the main reducer, torque was transferred to the operating drums in an arrangement similar to the original design. New shafting, couplings and bearings were designed for this purpose. The shafting, couplings and bearings will be larger to accommodate the additional power of the drive unit. The open gearing will be replaced on the operating drums. New bronze bushings will be provided to "replace in-kind" the existing bearings that hold the pinion shafts and the operating drums.

The operating ropes will be replaced due to wear. The operating drums themselves showed no signs of wear and are to be rehabilitated. The operating drums were slightly undersized by current AASHTO specifications for the drum diameter. It was decided to rehabilitate and reuse the existing operating drums since they have performed well over the years, and reuse will lower the project cost. The worm gear type take-up devices from the original bridge were not being used it is assumed because they were difficult to operate. The up-haul rope take-up had been bypassed completely and a come-along type tensioner device was being used. This device is to be replaced by an enclosed, worm gear driven, linear actuator. The down-haul take-up device was more difficult to access due to the small pier. It was decided to rehabilitate the original worm gear take-up device in this instance. An enclosed reducer will be coupled to the take-up device to make it easier to operate by allowing access from the deck via a long hand crank.

The balance system for the bridge will be rehabilitated as follows. The counterweight ropes had begun to show flat spots from wear and are in need of replacement. The counterweight sheaves were in an overall good condition and will be reused. The bronze bushings for the counterweight trunnions were assumed to be worn and are to be replaced in-kind. The deflector sheaves for the operating ropes were to be rehabilitated by boring the bronze bushings to a slightly larger diameter and using a new, slightly larger shaft to support them.