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Hydraulic Conversions of Movable Bridges

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Introduction

New movable bridges built using hydraulic machinery to power the mechanical systems are not uncommon. But there are a large number of older movable bridges with machinery that is difficult to access, experiencing wear, and possibly in need of replacement. For some of these bridges, converting to hydraulically powered machinery can be a benefit for maintenance, installation, and lifetime cost.

Presented here are two examples of movable bridges originally built with traditional electric motor and open gearing drive trains, which were converted to operate with hydraulic machinery, each with benefits to the specific installation. One is a highway double-leaf bascule, and the other is a railroad swing bridge. Both were built in the early 1900's and recently rehabilitated with new mechanical and electrical systems.

General Information

US-11

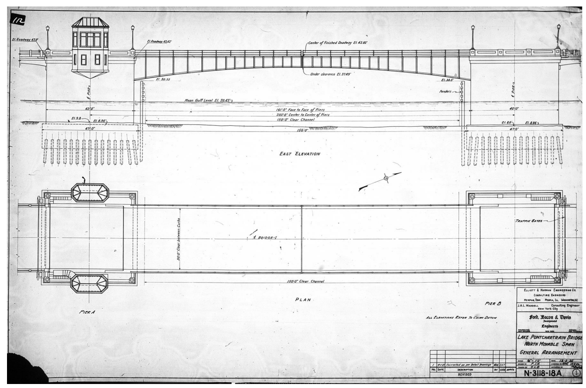

Figure 1 – US-11 General Plan and Elevation.

The US-11 bridge is approximately 5 miles long over Lake Pontchartrain near New Orleans, LA owned by the Louisiana Department of Transportation and Development (LADOTD), which contains two double-leaf bascule bridges. The bridge was originally built in 1928, carries two lanes of highway traffic, and the north movable span is 185 ft. between trunnions (see **Error! Reference source not found.**), which is the subject of this paper. The south movable span is slightly smaller, rarely used, and was converted to manual operation. The existing span drive machinery was located within the bascule leaf, with the motors, brakes, and first set of reduction gearing located on a stationary platform between the trunnions. Subsequent reduction gearing was located on the movable leaf itself, with the final pinion being at the rear end of the counterweight. This pinion engaged a stationary internal rack gear mounted in the counterweight pit (see Figures 2 and 3). The transition from stationary to moving machinery was accomplished by a bevel gear set located at the center of rotation of the leaf.

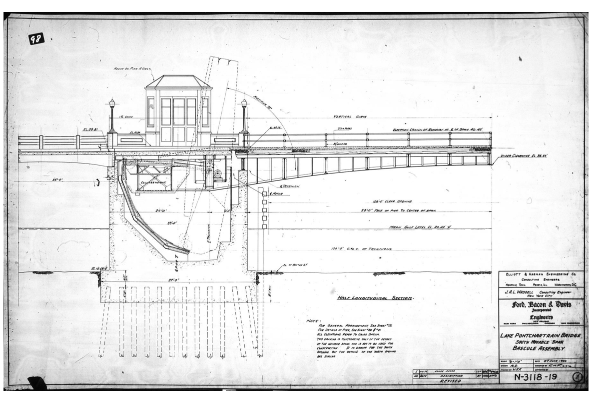

Figure 2 – US-11 Section View of Original Operating Machinery.

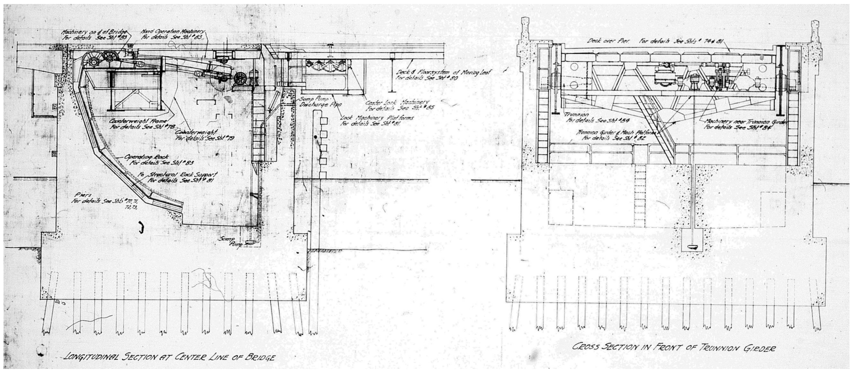

Figure 3 – US-11 Original Operating Machinery Layout.

Westlake

The Westlake bridge contains a through-truss swing span near Lake Charles, LA owned by Union Pacific Railway (UPRR). The bridge was originally built in 1906 and carries a single railroad track across the Calcasieu River. Each arm of the swing span is 111 ft with the turning machinery located on the swing span at the pivot pier (see Figure 4). Originally a single prime mover provided power for all mechanisms on the bridge. Open gearing and shafting were connected by clutches to drive the span as well as the end machinery. Over the years, the drive configuration had been updated so that electric motors powered the span drive machinery at the center, and electric linear actuators were installed to drive the various wedges, lifts, and locks.

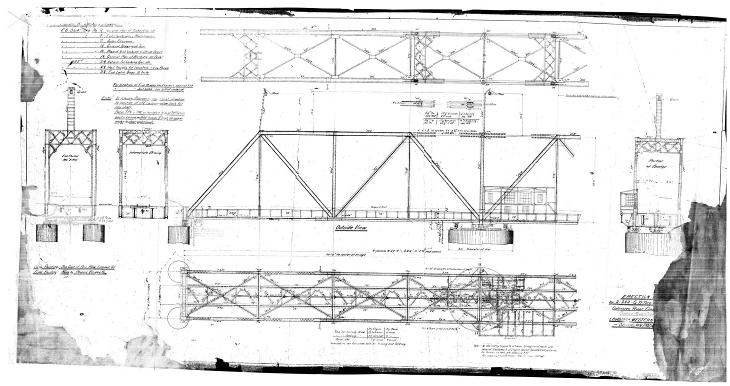

Figure 4 – Westlake General Plan and Elevation.

Need for Rehabilitation

US-11

While the span drive motors and brakes had been replaced in the past, the rest of the span operating machinery was original and experiencing heavy wear. The rack supports mounted in the counterweight pit had corrosion holes through the webs, compromising the securement of the rack in the span-raised position. The open gearing backlash had become excessive, and large spaces were present between the jaw coupling lugs, due to wear. Additionally, it was suspected that the trunnions were not in good alignment, due to reports from maintenance forces. The span occasionally had difficulty raising completely, and extra lubrication at the trunnions seemed to help. The trunnions had been removed and replaced previously, but alignment was unknown and difficult to check due to the operating machinery blocking line of sight between the trunnions. Following an inspection to determine a rehabilitation scope, LADOTD planned a full replacement of the mechanical and electrical systems.

Westlake

The bridge had seen increasing water levels and flood events. As such, there was concern that the electric linear actuators for the wedges and centering devices would be damaged in a major flood event, requiring repair or replacement with significant lead time for replacement components. Several linkages and supports for the center wedges were deteriorated. The span drive machinery had notable wear and deterioration throughout the system. Failures had occurred in one of the motor grid couplings and one of the primary reducers, the pinion shaft bearings had significant wear, and the pinion shaft bearings were not properly anchored. UPRR planned a rehabilitation of the mechanical systems of the bridge to increase reliability and reduce operational outages.

The Case for Hydraulic

US-11

LADOTD had decided that the rehabilitation should include replacement of the span operating machinery, mainly due to age and wear on the components. Initially, a span drive system with motors, brakes, and enclosed gearing was investigated. The primary drive machinery would be located on a platform between the trunnions, similar to the original, with shafts extending to the rear of the counterweight to drive the final gear reductions. Fitting new enclosed reducers in the available space was going to require custom gearboxes and intricate supports to interface with the existing structure. Also, significant alteration of the counterweight would be necessary to accommodate the large gearbox required at the rear end of the counterweight. Installation and alignment would also be difficult due to limited clearance and tight access in the machinery area. A new rack gear would be required, which would be anchored to the concrete wall of the counterweight pit. This rack would need to be positioned accurately on the center of rotation of the bascule leaf. This alignment would likely require the leaf to be operated to check radial runout of the rack, prior to permanently securing the rack. While possible, this entire effort was admittedly challenging.

LADOTD has several movable bridges that are hydraulically powered, so their bridge design and maintenance groups are already familiar with hydraulic machinery. With the difficulties facing a traditional machinery replacement, hydraulic options were investigated. Briefly considered was a pair of hydraulic motors directly driving the pinion at the rear of the counterweight. However, this still required a rack gear replacement, and significant alteration of the counterweight. Another option was to add hydraulic cylinders beneath the bascule girders to directly push/pull the span up and down. The counterweight pit was sufficiently deep for the length of cylinder required, and a walkway existed at the front pit wall, allowing for easy access to the cylinder manifold, hoses, and upper connect. Another benefit was that the cylinder option allowed for installation of the new hydraulic components while the span was still operable with the existing machinery. LADOTD agreed that the cylinder-driven span concept was the best option and detailed design proceeded.

Westlake

The rail lifts on this bridge had recently been retrofitted with hydraulic cylinders, and a small HPU was installed at the center of the span to operate them. Due to the flood concerns for the wedge linear actuators, UPRR expressed a desire for systems that would be less impacted by flooding. Converting these systems to hydraulic cylinder operation was proposed as a more flood proof solution.
The replacement span operating machinery was initially intended to be powered by new electric motors and enclosed gearing. However, these motors would still be located at a level which could be affected by a flooding event. Due to this concern, and the rest of the systems on the bridge being converted to hydraulic, it was proposed that the span be driven by hydraulic motors. These motors could be powered

by the same HPU as the ancillary systems without adding significant complexity. Also, the electric motors and other electronic components on the HPU would be located above flood level with easy access for maintenance. With the potential benefits of having all systems powered hydraulically, UPRR agreed with the concept and directed detailed design to begin.

Design Details

US-11

While the span operating cylinders would be located in the counterweight pit, the HPU was required to be place at roadway level to avoid flood risks and improve access for maintenance. On the south leaf, the existing generator house would be used for the south HPU. The north leaf had no existing location for large equipment, so a new building was planned directly next to the roadway on the north leaf. This new building would house a new generator, the north HPU, and serve as a storage location for maintenance equipment (see Figure 5).

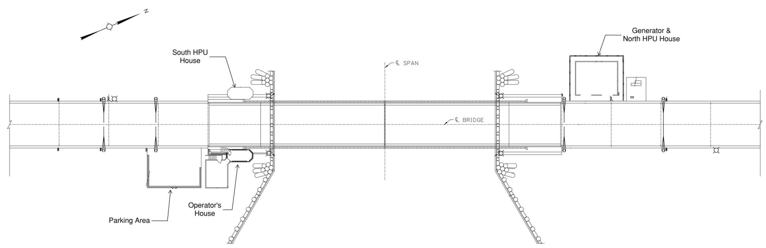

Figure 5 – US-11 HPU and Operator House Locations.

Geometry for the span cylinders was optimized to minimize stroke length while having sufficient moment arm lengths at the span-seated and span-raised positions. This optimization exercise looks at bore size, rod size, extended length, and buckling resistance, in an effort to keep operating pressures and flow rates within reasonable limits. All while ensuring the cylinder does not interfere with the span and counterweight pit walls. Once the span cylinder geometry is set, and operating pressures are known, the hydraulic pump and electric motor sizing can be found. The final cylinder details are 12 inch bore, 7 inch rods, and 119 ½ in stroke, with adjustable cushions at both ends. The bore end is pinned to a support in the counterweight pit, and the rod end is pinned to the underside of the bascule girder. Both ends have spherical bearing connections (see Figure 6).

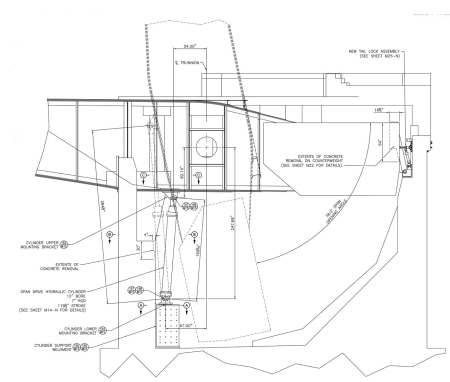

Figure 6 – US-11 New Hydraulic Cylinder Layout.

Since the cylinders are single-ended (no through-rod), an open loop pump was chosen to keep the circuit simple. Two electric motor/pump groups are used, each with capacity of providing half of the full required flow. Both pumps operate together during normal operation, and if one pump is not operable, the bridge moves at half speed. This provides redundancy without requiring larger size motors and pumps.

Pressure compensated pumps were selected for control simplicity. These types of pumps attempt to maintain a constant pressure at the pump outlet. They produce full flow until a pre-set pressure is detected, at which time the pump reduces flow output. If pump outlet pressure drops, flow increases, and vice versa. Flow rate is controlled by gradually opening a valve to allow the pump to smoothly increase flow. The final circuit includes two 71 cc pressure compensated pumps driven by 50 hp constant speed electric motors. Speed and acceleration are controlled by a pair of proportional directional control valves. LADOTD uses relay logic for the bridge control circuitry, and for the proportional valves to be compatible, the ramping and speed controls are pre-set in the proportional valve amplifier. The span control system energizes relays, which send commands to the amplifier for full and creep speeds for raising and lowering. Counterbalance valves are used to control overhauling loads, and cylinder-mounted relief valves are used for holding the span in the raised position.

The hydraulic power unit (HPU) was arranged with maintenance in mind. There are two return fluid filters which are used one at a time. When one starts to clog, flow can be switched to the other while the clogged filter is being replaced. An in-line heater is included in a fluid conditioning loop, with a small pump and motor. This loop circulates the oil when heat is required, dispersing warm oil more effectively. Also, the heater can be replaced without draining the reservoir. The fluid conditioning loop contains quick connect fittings that can be used to drain and fill the reservoir. Fluid added to the reservoir flows through the filter, eliminating the need for a separate filtering cart.

In addition to the span drive machinery, the center locks were replaced, and new tail locks were installed. In an effort to keep the span drive HPU less complex, these mechanisms are powered by small, simple HPUs dedicated to operate each set of locks.

Westlake

The existing span drive configuration included two pinions engaging a curved rack fixed to the pier. For the new arrangement, two hydraulic motors each drive a final pinion, with a right-angle speed reducer included to decrease the physical size of the hydraulic motor needed. Including a reducer also allows the use of a drum brake to be included in the design.

The existing span drive arrangement allowed for operation on a single pinion, and UPRR desired to keep this capability. Sizing of the hydraulic motors was performed assuming both pinions operate under normal AREMA loading. However sizing for single pinion operation under this loading would require larger pinions and larger motors. A compromise was made to size single pinion operation for AREMA Condition A loading only, and provisions to adjust pressure settings and isolate the motors from the circuit were included in the design. Each pinion would be driven by a 332 cc fixed displacement radial piston motor, with a 63:1 right-angle speed reducer (see Figure 7).

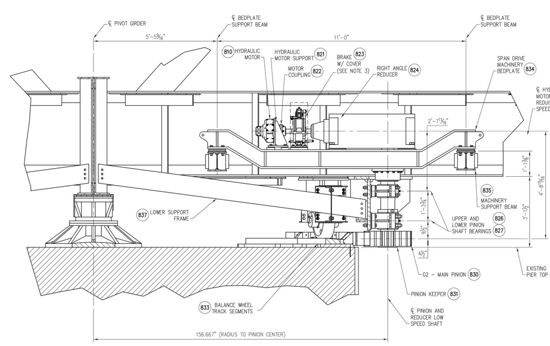

Figure 7 – Westlake New Machinery Layout.

Since the span drive hydraulic motors would be powered using the same pumps as the ancillary systems, an open loop circuit was chosen so that only one pump would be required per electric motor. The HPU contains two motor/pump groups that operate simultaneously, with each pump providing half of the flow required for full speed operation. Similar to the US-11 design, this provides redundancy without needing two full size pumps and motors. Two 18 cc open loop, pressure compensated pumps are used for span operation and for the ancillary devices, each driven by a 20 hp electric motor. Proportional directional control valves are used to control speed and acceleration of the span, and standard directional control valves are used to operate individual ancillary systems. Counterbalance valves are included to control overhauling loads on the span drive.

For braking, the hydraulic motors and circuit are sized to perform the function of motor brakes. A drum brake is included between the hydraulic motor and right-angle reducer to perform the function of the machinery brake. The combined action of the hydraulic circuit and the drum brake hold the span against wind loads.

All ancillary devices are driven by hydraulic cylinders equipped with pilot operated check valves to hold position when depressurized. Vertically oriented cylinders have counterbalance valves to control the downward movement, and the rail lift cylinders use flow dividers so two individual rails are lifted at the same rate. Since the required system pressure for some of the ancillary circuits needs to be lower than the standard system pressure, external pressure compensator setting valves are used to lower the pump pressure when those devices were operated. This consists of a separate pressure relief valve with a solenoid operated directional valve for isolation. When a lower system pressure is needed, the directional valve is actuated, connecting the relief valve to the pump’s external compensator port.

An auxiliary drive option is also included in the HPU. A 5.6 cc, fixed displacement, open loop gear pump, driven by a 5 hp motor, is provided for auxiliary operation. Similar to the main pumps, the auxiliary pump can operate all of the ancillary devices as well as the span drive machinery. Auxiliary operation is intended to be performed manually since all safety interlocks are bypassed. To engage the auxiliary pump, a valve is shifted with a hand lever to provide pressure to the manifold. From there, the directional valves for the ancillary devices can be actuated by hand. Also, a separate lever-operated directional control valve is provided to provide flow to the span drive motors.

Construction

US-11

The span operating cylinders were custom designed for this application, with cushions sized specifically for the bridge inertia and pump flow. The cylinders cushions can decelerate the span from full speed to creep, with pumps at full speed flow, allowing the span to reach fully raised or seated safely in the event of a control system failure where the span did not decelerate. After the cylinders were fabricated, the cushion performance was tested in the shop, in addition to standard cylinder pressure testing (see Figure 8). A test HPU was used for cushion testing, which was set to match the pressure and flow rate representing full speed operation. The cylinders were operated at full speed into the cushions. Pressure and stroke were recorded at several settings of the cushioning valves to find optimal settings for smooth deceleration.

Figure 8 – US-11 Hydraulic Cylinder Shop Test.

During construction, the span continued to be operated on the existing drive machinery while the new cylinder attachments were installed in the counterweight pit and on the bascule girder. After the new HPU, piping, and electrical controls were installed for the new span drive system, the cylinders were pinned in position and connected to the hydraulic system, making the span ready for operation on the new system (see Figures 9 and 10).

Figure 9 – US-11 View of Installed Hydraulic Cylinder.

The proportional directional control valves were preset in the shop at approximate values for full and creep speeds of the span. These settings need to be fine-tuned once the full system is operating the bridge. By observing span operation and recording operating times, incremental adjustments can be made until the acceleration ramps and operating speeds are as desired.

Figure 10 – US-11 View of Installed HPU.

Once the bridge operating speeds were set, field testing of the span cylinder cushions was performed. Cushion testing of the US-11 cylinders was carried out progressively, with tests starting at 25% of full speed, with subsequent tests gradually increasing to full speed. The span was raised until the cylinders had extended about 2 feet. The span was then lowered to the fully seated position without decelerating. Pressure and stroke were recorded to monitor the cushioning pressures and speed. At higher span speeds, cushion pressures increased and adjustments to the cylinder cushion valves were made to match pressures on the two cylinders as closely as possible. Once cushion pressures matched fairly well, the bridge was operated at full speed into the cushions. Visually, it is imperceptible that the span is operating out of the ordinary. The cushions decelerate the span to a slow speed and the span lands gently on the seats, similar to a normal operation. The same testing is performed at the fully raised position, after which the cushion valve settings are recorded and should not need to be adjusted again. The span will always decelerate safely before the cylinders reach the end of stroke, even if the control system does not slow down the bridge.

Westlake

The Westlake rehabilitation needed to be performed without taking the bridge out of service for railway traffic, and with limited outages to marine traffic. To facilitate continued operation, a temporary balance wheel track was included in the design while the new track and rack segments were installed and aligned (see Figure 11). The suggested sequence had half of the rack being replaced first, then switching operation to that portion of the new rack while the second half was replaced. However, the contractor elected to use an external temporary means of operating the bridge and replaced the whole track and rack at once, which simplified the alignment process.

Figure 11 – Westlake Temporary Balance Wheel Track and Partially Installed Permanent Balance Wheel Track.

Figure 12 – Westlake View of Installed Pinion and Bearings.

The hydraulic cylinders for the wedges, rail lifts, and centering devices were installed first so that those systems could be operated hydraulically during the manual span operation. For the span drive machinery, the rack segments were aligned to the center of rotation first, then the new pinions were installed and aligned to the racks (see Figure 12). The new hydraulic span drive motor, brake, and right-angle reducer had been shop aligned on a bedplate so that they could be placed into position as a unit (see Figure 13). This assembly was aligned to the pinion shaft as the last major component of the span drive installation. Once in position, the hydraulic motor could be connected to the hydraulic system, tested, and put into service.

Adjustments to the proportional directional control valve were made to set acceleration ramps and span speeds so that the bridge operated as intended.

Figure 13 – Westlake View of New Machinery Bedplate Assembly.

Summary

The reasons for converting the US-11 and Westlake bridges to hydraulic operation were different, but both bridges share benefits from the conversion. Maintenance can be concentrated and located in a convenient spot for easier access. Individual actuators are easier to procure and replace if needed. And the electrical portions of the span operating machinery are more flood resistant since they can be located at a higher elevation. Hydraulic operation may not be the best solution for every movable bridge rehab, but in many cases, it is an option worth considering.