**HEAVY MOVABLE STRUCTURES, INC.**
**TWENTIETH BIENNIAL SYMPOSIUM**

October 7-10, 2024

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# The Rehabilitation of the Rio Vista Bridge

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# Introduction

The Rio Vista Bridge is a vertical tower lift bridge located on the Sacramento River. In 2018, the 306-foot movable span became stuck in the fully raised position for several hours. While the bridge was eventually lowered, the original machinery was deemed unusable, rendering the bridge inoperable. As a main shipping channel for Yolo County and the Port of West Sacramento, the Rio Vista Bridge was considered too critical to remain out of service. The California Department of Transportation (Caltrans) took immediate action to redesign and rehabilitate the bridge's electrical and mechanical components while minimizing closure times. The goal was to modernize the bridge and incorporate multiple redundancies and fail-safes to prevent failures that could lead to extended periods of inoperability. By the end of 2023, with the assistance of several consultants and contractors, Caltrans successfully completed the project. This paper focuses on the design and rehabilitation of the Rio Vista Bridge while keeping it operational throughout construction.

# Background

## History

The Rio Vista Bridge officially the Helen Madere Memorial Bridge named after Helen Madere, was originally a bascule bridge first built in 1918 and opened in January 1919. This bridge was reconstructed, becoming a tower bridge on 1943-1944 and first opened April 1, 1960. Providing a two-lane roadway and two sidewalks, the bridge stretches a total length of 2890 feet and 30.5 feet wide. The 1,550,000 pound movable span itself is 306 feet.  Rio Vista is one of several movable bridges in the Sacramento-San Joaquin River that serves as a route for vessel traffic to the Port of West Sacramento and Yolo county.

Figure 1: Rio Vista Bridge

## Original Design

Each end of the movable span is connected to a counterweight, approximately weighing 771,000 pounds, with 40 2” 6x19 wire ropes. At the top of each tower, the two sheaves carrying the wire ropes are connected to the low speed, L.S, shaft of a differential gear box. Two 30 HP motors are connected to the high speed, H.S, shaft via eddy-current clutches. One motor to raise and the other to lower the movable span. Braking control was achieved by the combination of the two motors by engaging a percentage of torque through the eddy-current clutch. The electric drum brake was between the raise motor and the gear box. A tachometer on the H.S shaft was used to detect and shut down overspeed. A selsyn drive, located on the L.S shaft, was used to match rotation between the two towers and prevent skew. A series of limit switches, located at the West pier, were used to reduce motor speeds until finally hitting the corner seated limit switches. A duplicate set of limit switches were used for the fully raised, located above the bridge house, triggered the reduced speeds as the counterweight lowered.

## Incident

On Thursday, August 9th, 2018, Rio Vista Bridge skewed more than the allowable 5” while lowering from a fully raised position. The skew alarm triggered an automatic stop, setting both motor brakes. Electricians and the bridge operators attempted to correct the skew with the override button. The bridge lowered a few feet but continued to skew until finally stopping at 70’. Mechanical and electrical engineers came onsite and began to troubleshoot. Finding that the East side was higher than the West, the engineers attempted to lower it by using the manual hand crank. It was discovered that the H.S shafts of the gear box were turning, but not the L.S, shafts. Inspecting the East gear box, the engineers found that the main herringbone gear was floating on the L.S. shaft. The bridge was eventually lowered by carefully backing off the holding torque on the West brake and “feathering” bridge down with gravity.

With the East gearbox declared as critical failure, an emergency directors order was initiated that led to hiring Golden State Bridge, GSB, to remove both gear boxes. The gear boxes were sent to Steward Machine, to be inspected and repaired. The East gear box had broken teeth on several gears, and the West gear box teeth had stress fractures discovered through NDT techniques. The manufacturer began to repair the gear boxes and replace the broken components.

Figure 2: East Gear Reducer, Broken Gear

While the gear box was being repaired, engineers inspected the remaining components of the bridge. Having found that all the motors had relatively low insulation resistance, they were sent to Dahl-beck Electric to be repaired. In addition, several seating limit switches were found faulty, leading engineers to speculate that the skew issues originated during the seating sequence.

## Manual Operations

Anticipating a month lead time for gear box repairs, Caltrans came to an agreement with the Coast Guard, USCG, to have scheduled openings for vessels on the weekend nights. During these nights, Caltrans developed a plan to lift the movable span manually, leaving the water way open each night from 8pm to 6pm. The roadway would be closed to vehicular traffic for the duration of the night.

The plan involved pulling each of the two counterweights down. Two ¾-inch wire ropes were tied around each counterweight that fed into a winch on the roadway level. Bridge elevation change was monitored with tape measures attached to the movable span and digital range finders targeting the counterweight. During lifting procedures, each winch would pull down the counterweight in 5 foot increments. Elevation changes were compared between span ends on each interval to prevent skew. Several teams were distributed throughout the span to ensure no issues would occur. When the bridge was at the fully raised position, the sheaves were tied to the structure to lock the span in place.

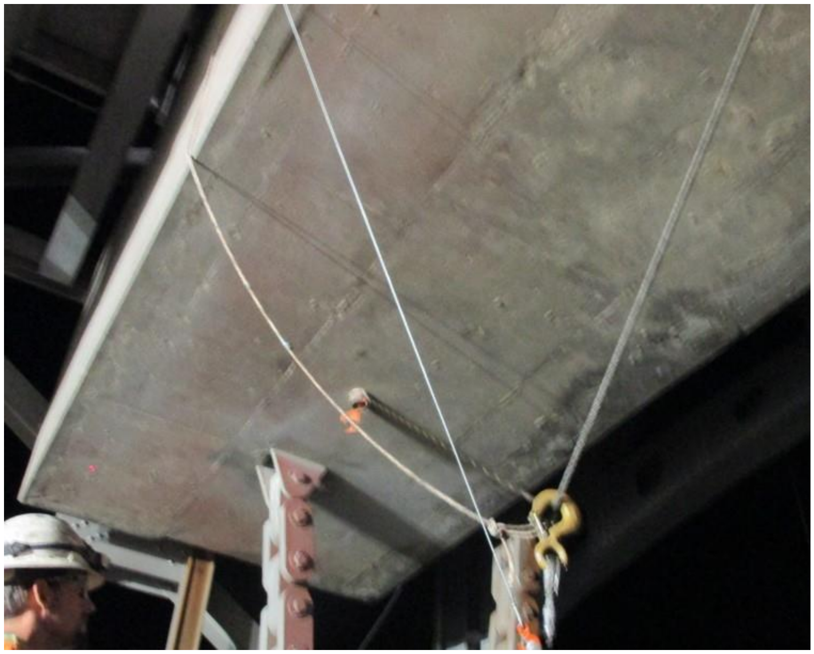

Figure 3: Counterweight pulled down with a winch to raise the movable span.

On September 14, 2018, with the installment of the refurbished gear boxes were installed and replacement of faulty equipment, the movable span was back in service. Engineers were tasked to replace the mechanical and electrical components of the movable span to prevent this issue from reoccurring.

## Design Planning

The Electrical, Mechanical, Water and Wastewater Branch, EMWW, of Caltrans began designing the new mechanical/electrical system, replacing the existing system with a modern design. Unfortunately, installing an entirely new system required the bridge to be inoperable for a period of time. This was not an option with USCG as they required the channel to be open to vessels on call. In lieu of this, EMWW designed a temporary control station to control all the traffic closure devices (traffic signals and sirens, traffic gates, popup barriers). Though, the means to operate the movable span during construction remained in question.

The Structural Construction Branch of Caltrans reached out to Hardesty and Handover, H&H, for suggestions on keeping the bridge operational during construction. Creating an entirely new system that would run in parallel with the existing was proposed. A separate drive system would be mated to the sheave ring gear and would not interfere with existing nor the construction of the new system. This would also serve as a backup system and meet the goal of redundancy.

Rehabilitating Rio Vista Bridge was broken down into three stages. First stage was to install a temporary traffic control system that would work with the new Backup System. The existing system would be in operation during the first stage of installation. The second stage was to demo all existing equipment once the movable bridge was successfully operated with the Backup System. The third stage was to install the new Main System, while operating under the backup, until completion. After the third stage is completed, the backup system would be disengaged and remain for emergency use.

# DESIGN AND INSTALLATION

## Backup System Design

For the development of the Rio Vista backup system, initial design concepts based on similar approaches used in other bridge and heavy movable structure projects were created. The Rio Vista Bridge, located along a critical shipping channel to the Port of Sacramento and spanning SR-12, posed specific constraints. As noted, the USCG would not allow for the span to be closed in the seated position for extended periods of times, and the work for the main system could not be done with span in the raised position due to the significant roadway detour that it would create. In response, the use of independent slewing planetary gearboxes paired with C-face mounted inverter duty motors was proposed. These systems would be electrically linked via flux vector drives and an Ethernet-based PLC system, designed to accommodate the temporary construction conditions.

The selection of planetary gearbox assemblies was driven by the need to minimize construction costs, streamline equipment procurement which allow for project continuity during construction. These assemblies would utilize new pinions that would engage with the sheave ring gear at new positions. Two initial design concepts were developed and presented, each tailored to meet the functional and operational requirements of the project

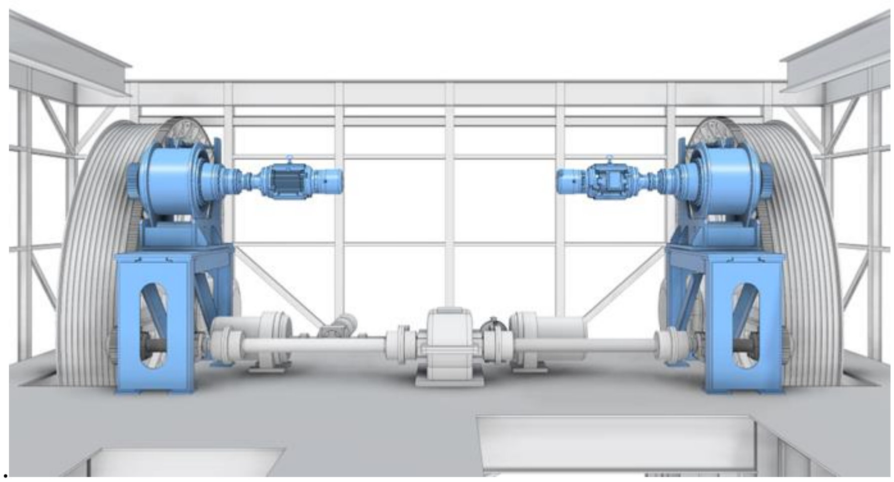

Figure 4: Backup Drive System Concept 1

Option one involved straddling the existing main pinions while maintaining a clear central workspace during the construction of the main system. This design facilitated the installation of the backup operating machinery at a lower elevation, which enhanced future system maintenance. By positioning key components in this manner, the design improved accessibility and minimized disruption, providing a more efficient layout for both construction and long-term upkeep.

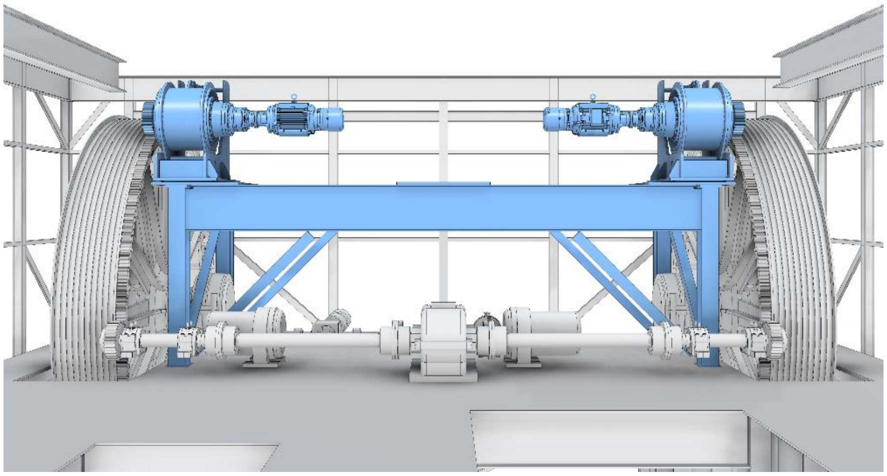

Figure 5: Backup Drive System Concept 2

The second option proposed straddling the inboard trunnion bearings of each sheave, with the operating machinery positioned at a higher elevation. This configuration allowed for the incorporation of cross members to stiffen the operating machinery and also provided a platform for maintenance access to the equipment.

After presenting and discussing both options, Caltrans selected Concept 1 as the preferred alternative. The lower elevation of option one aligned with the installation of a new maintenance bridge crane, minimizing potential issues and simplifying access for future maintenance tasks.

Throughout the initial concept development, it was agreed that regardless of the selected option, the installed system would remain permanently in place as a backup means to operate the bridge once the main system was completed. To enable this, the planetary gear assemblies were designed to be installed in a swing bracket frame assembly. The pinions could be manually engaged or disengaged using a turnbuckle assembly located at the top of the frame. The position of the backup drive system would be monitored by proximity sensors mounted at the hard stops of the swing bracket, ensuring reliable operation and precise monitoring during both regular and emergency use.

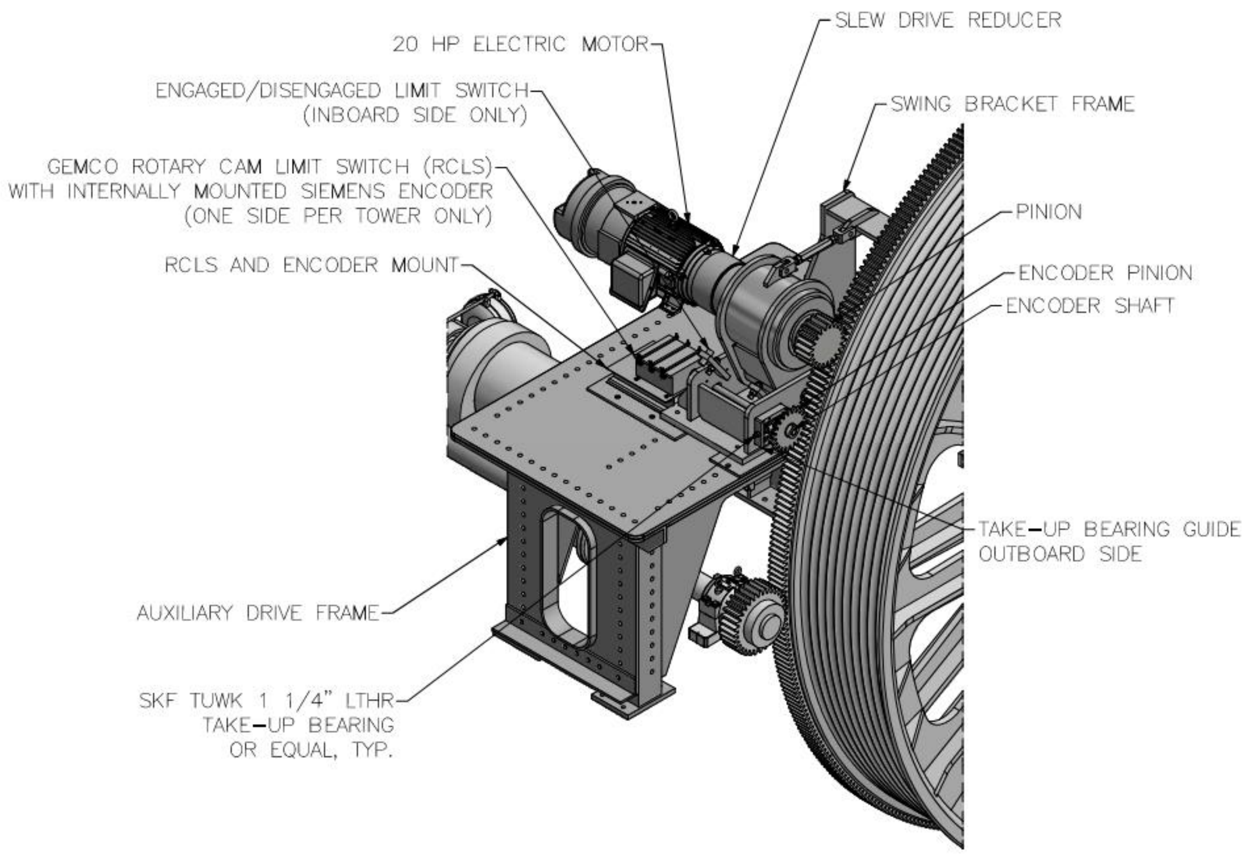


Figure 6: Backup Drive System Assembly

The backup system was designed around Siemens control equipment. Initially, the new main system was planned to utilize all Siemens components. The PLC system comprised a SIMATIC S7-1200 series processor and ET200 distributed I/O systems, with inverter-duty motors controlled by Siemens G120 drives. Siemens G120 drives are modular frequency converters that provide flexibility and ease of maintenance. These drives consist of a Control Unit (CU), Power Module (PM), and Operator Panel (Basic Operator Panel). Unlike other manufacturers, where drives are typically ordered as a single assembly, Siemens requires more coordination in selecting components for their variable frequency drives.

Wireless communication was incorporated into the system due to uncertainty regarding the installation timeline of new submarine cables.

During the procurement and fabrication of the backup drive control system, vendors without experience in movable bridges and heavy movable structures were deliberately excluded. Given the urgency and tight timelines of the project, Caltrans sought assistance from Panatrol to provide the backup control system equipment. By the time Panatrol became involved, key components—such as power modules and resistor banks—had already been selected from prior vendors.

A significant challenge during the development of the Backup System was the use of Siemens-brand equipment, which was unfamiliar to Panatrol. However, by leveraging years of industry expertise, Panatrol overcame this challenge through collaboration with trusted vendors and additional resources. With extensive experience in designing control systems for movable bridges, Panatrol was able to efficiently convert Allen Bradley, GE, and Emerson function blocks into Siemens function blocks, ensuring the Backup System was completed smoothly by streamlining control logic using familiar methods.

As many control system vendors would agree, some aspects of bridge control are straightforward, while others are more complex. For example, controlling a traffic gate is relatively simple: a command is sent to raise or lower the gate. Similarly, basic span movement commands are straightforward. However, maintaining strict control over the span's skew—ensuring it remains within an 8-inch tolerance between towers—adds significant complexity. Panatrol's proprietary skew routine, developed for Allen Bradley, GE/Emerson, and now Siemens, provided precise control over the speed of the drives, ensuring the span stayed within the required 8-inch tolerance across its 126-foot length.

Panatrol swiftly procured, assembled, and programmed the equipment. During this process, a motor and drive test was conducted, revealing that the braking resistors, previously selected by a party no longer involved in the project, were incorrectly sized for the duty cycle required for heavy movable structures. Additionally, it was found that the internal braking chopper of the Siemens power module could not support the 150% braking torque current required. To resolve this issue, an external braking chopper from Bonitron, along with properly sized Bonitron braking resistors, was provided. Within a few weeks, the new equipment was installed, tested, and proven to function properly before being shipped to the field for final installation.

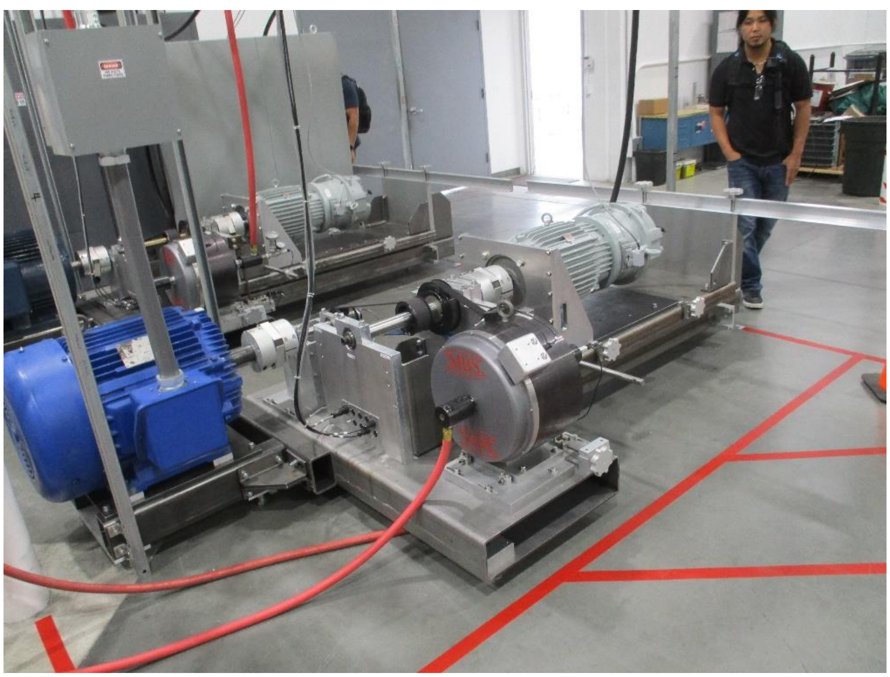

Figure 7: Backup System Motor Drive Testing

Installation of the backup machinery proved to be difficult, as the existing system was still in operation. Since both water and roadway could not be shut down, vessels were requested to schedule 4-hour openings during construction. This allowed HMI, millwrights, to connect the backup machinery to the existing sheave ring gear within open windows. Alignment of gear mesh and proper backlash were tested several times by engaging the backup motor, releasing the brake to allow free spin, and operating the existing system.

During the commissioning of the Main System, an operator remarked on the remarkable performance of the Backup System, noting that it consistently maintained bridge skew throughout the entire span's travel. This observation raised the question of whether a Main System was even necessary, given the high level of performance achieved by the Backup System.

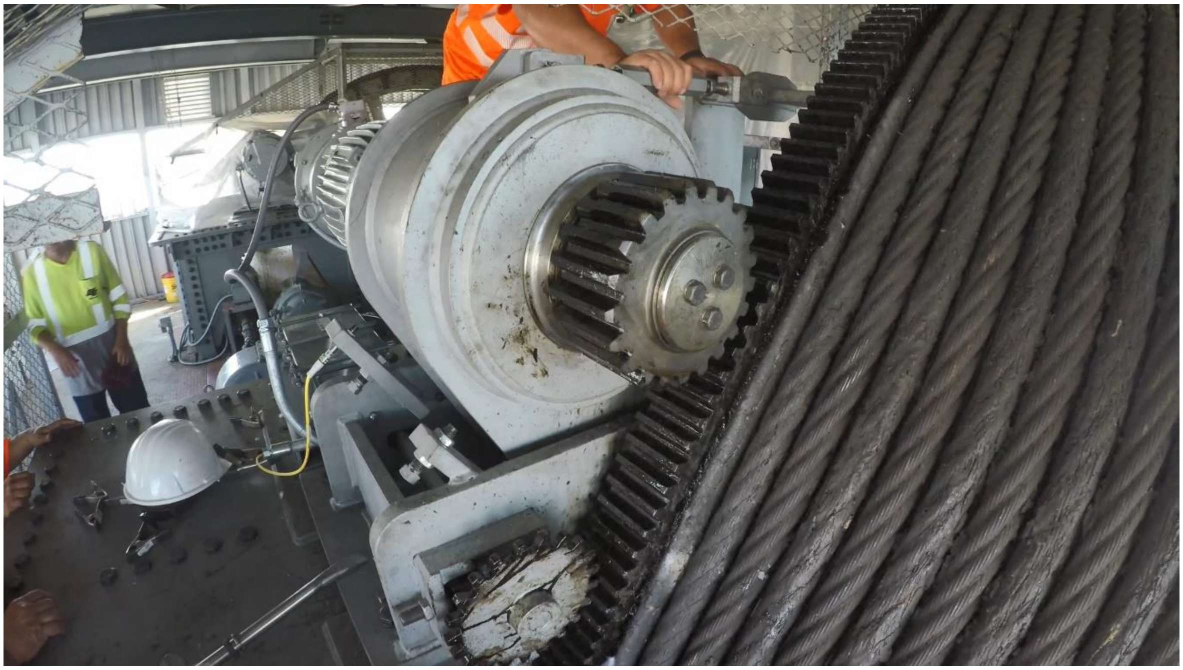

Figure 8: Backup Drives Engagement to the Sheave Ring Gear

## Main System Design

The machinery components in a single tower include two 40 HP, 1200 RPM motors with back-end thruster drum brakes. Each motor is integrated with an incremental encoder for speed feedback to the VFD. One motor per tower is used to raise and lower the movable span, while the second motor serves as a backup, free-spinning when not in use. Through PLC controls, operators can switch between the two motors. Both motors are connected to the high-speed shaft of a 60:53:1 Nuttal differential gear reducer. On the low-speed end, the output shaft, with a pinion gear pressed onto it, is mated to the existing sheave ring gear. The output shaft includes a floating shaft and a pinion shaft, both supported by two bearings and connected via a Rigid/Flex coupler.

The machinery brakes are adjustable 4,500 ft-lb thruster disk brakes, each with a 25-inch disk bolted to the rigid coupler of the gearbox. The motor brakes and machinery brakes are set with a hydraulic delay of 2 and 4 seconds, respectively. Each pinion shaft features a Avtron absolute encoder, connected via a 1:1 gear/pinion, to track the position of each side of the movable span. One absolute encoder ensures the movable span ends stay aligned to prevent skew, while the second pair of absolute encoders serves as a backup should the primary encoders fail.

Similar to the backup drive installation, 4-hour schedule vessel openings were still in effect. Precision alignment was more critical than installing the backup drive as the sheaves shared a common shaft line.

Being 200 feet apart, HMI scheduled vehicle closures, ranging between 10-20 minutes to reduce vibration. The reduction in vibration allowed HMI to use a laser and rotoalign the output shafts between main gear reducer to both ring gears.

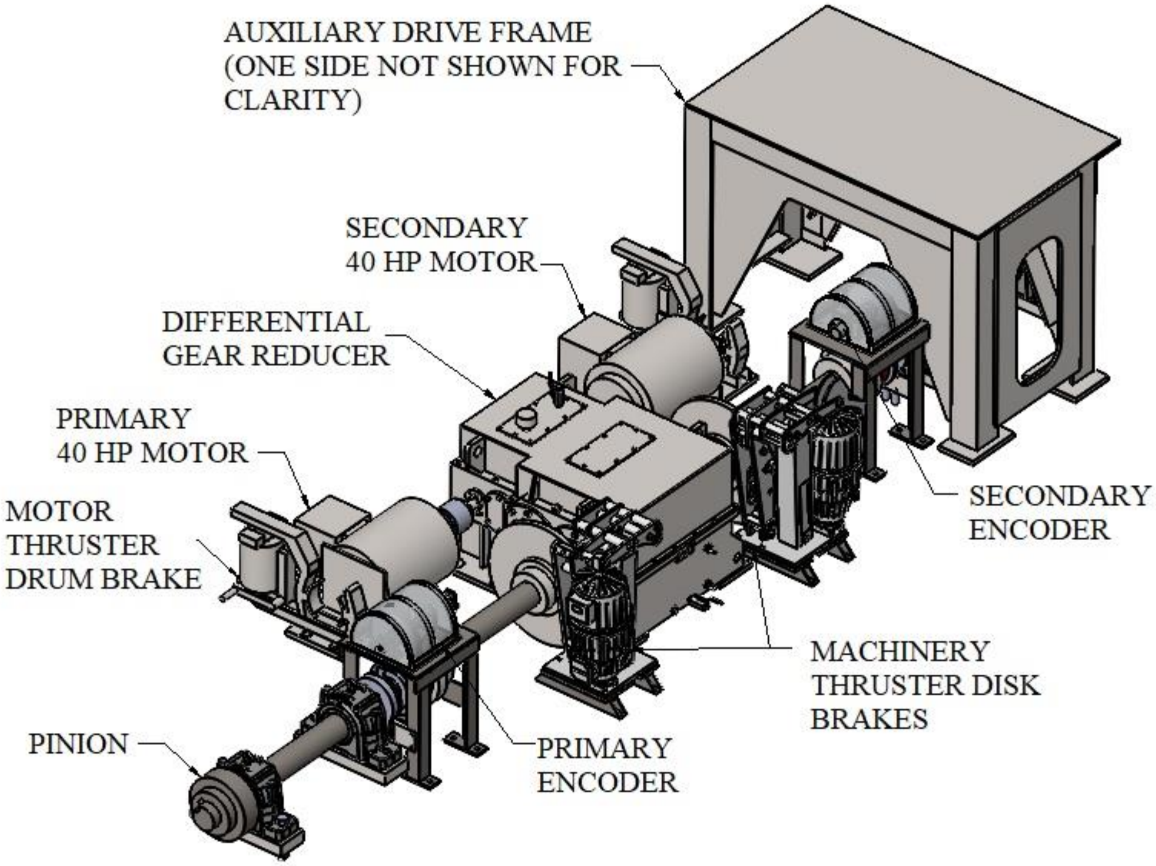


Figure 9: Main Drive System Assembly

The Main System consists of an Allen Bradley Hot Redundancy PLC, 4 AB PanelViews, and 4 Danfoss Drives. The overall control system includes 2 PLCs, 3 I/O racks, 8 traffic gates, 2 traffic barriers, 2 pedestrian gates, 4 span locks, 4 machinery brakes, 4 motor brakes, 4 speed encoders, and 4 absolute position encoders. Developing the PLC control system was challenging due to the complexity and the volume of equipment. However, Panatrol's familiarity with Allen Bradley systems allowed for the successful development of both PLC and HMI logic within six months. The presence of a fully functional and operational backup system provided the opportunity to scale the 4 absolute position encoders without impacting the span's operation. The proprietary skew routine allows the span's skew to be controlled within 8 inches when using the backup system, while the Main Control System maintains skew under 4 inches throughout the span's travel. The difference in skew precision is due to a mechanical bind in a specific section of travel when using the backup system, which the Main System can drive through more effectively.

Initially, Panatrol was tasked solely with providing the controls for the drives in the Main System. Danfoss Drives were selected due to familiarity and proven reliability in previous movable structure projects. However, after further discussions to alleviate the workload on the Main Control System

Vendor, Panatrol was also tasked with developing the PLC/HMI logic for the Control System. This added responsibility introduced challenges, as developing both hardware and software proved to be a more complex task than anticipated.

Despite the challenges, the project had several key successes:

- Familiarity with the equipment.
- Implementation of a proprietary skew control routine.

Several issues arose during the development of the Main System:

- The project was classified as an emergency repair, resulting in a time-and-materials (T&M) structure.
- The Main Control System Vendor lacked knowledge specific to bridge control systems.
- There was limited control over the entire system.

Emergency repairs and T&M projects often present financial challenges, and this was encountered on the Main System. One instance involved verifying signals for the near-side machinery and motor brakes. It was discovered that signals for Motor Brake 2 had been swapped with Motor Brake 4, and Machinery Brake 6 had been swapped with Machinery Brake 8. Contractors, unfamiliar with bridge systems, swapped the connections in the machinery room. After verification, they later swapped connections at the MCC, ultimately returning the signals to their incorrect configuration. Since the project was T&M, the contractor was compensated multiple times for addressing the same issue.

The Main Control System Vendor received the contract due to the emergency nature of the repairs, despite a lack of experience with movable structures. This lack of expertise became evident when the vendor treated the project as if a simple I/O checkout during the Shop Factory Acceptance Test or Site Acceptance Test would suffice. The vendor did not fully understand that the control system included a PLC system running in parallel with a fully operational relay system, a concept unfamiliar to them.

Another major issue arose just before night commissioning. A test was conducted to ensure the system was ready for span commissioning, which involved operating the traffic devices and verifying the PLC was prepared to move the span. However, the PLC failed to communicate with the necessary components. Further investigation revealed that the Main Control System Vendor had changed the port configuration used for communication with the HMIs, VFDs, and I/O racks. The managed switch required specific network devices to be connected to specific ports, and the ports that had worked during the PLC wakeup were no longer the same. Access to reconfigure the switch was locked by the Main Control System Vendor, delaying resolution. It took over four hours, with teams working from three different locations (on-site, the Main Control System Vendor, and Panatrol), to have the Main Control System IT department modify the switch configuration. Once communication was re-established, the test proceeded without further issues.

Upon completion of the Main System, the difference between developing software alone and developing both software and hardware for a system became evident. When a Control System Vendor is responsible for everything, they typically have thorough knowledge of the digital inputs and outputs, network infrastructure, sequence of operations, and field equipment/devices. Additionally, when vendors develop the hardware, they tend to select components they are familiar with and have successfully used in the past.

Figure 10: Installed Main Operating Machinery

# CONCLUSION

In 2018, the Rio Vista Bridge machinery failed during a vessel opening, leaving the existing equipment unable to lift or lower the span. This failure severely impacted vessel traffic along the Sacramento River, a key shipping channel. In response, Caltrans initiated a project to modernize the Rio Vista Bridge by incorporating modern equipment, enhanced safety provisions, and redundancies. Anticipating lengthy construction periods that would otherwise require shutting down the movable span, a backup drive system to maintain span operations during construction was implemented. This approach allowed the team to significantly improve the bridge without heavily disrupting road and waterway traffic. The new control system developed by Panatrol not only introduced safety features to prevent future failures but also provided enhanced operational reliability.

The Rio Vista Bridge failure spurred a long-term improvement plan for several other movable bridges in the Delta region, with Rio Vista serving as the first and most challenging project. The lessons learned during the rehabilitation of Rio Vista have allowed Caltrans and the project team to refine their approach for the other bridges currently under construction. These improvements have refreshed the mechanical and electrical systems, while also enabling the creation of comprehensive as-built documentation and O&M manuals. This will ensure that future staff have the necessary resources to properly maintain these systems and help prevent any major failures from occurring in the future.