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HNTB
"Teamwork and Planning Replace Mech & Electr Sys - RR Bridge"

TEAMWORK AND PLANNING REPLACE MECHANICAL AND ELECTRICAL SYSTEM ON BURLINGTON NORTHERN RAILROAD BRIDGE IN SEATTLE, WASHINGTON

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INTRODUCTION

On Saturday, April 18, 1992, at 8:00 A. M., two days ahead of a permitted seven day replacement schedule, the Burlington Northern double track single leaf heel trunnion bascule bridge was raised to again permit navigation thru the channel opening at the mouth of the Lake Washington Ship Canal in Seattle, Washington. This raising of the leaf reopened the channel after completely removing the existing machinery and electrical system and installing a new mechanical and electrical drive and control system. This was the culmination of a project which had started over 18 months previously when the Burlington Northern Railroad contacted the firm of Howard Needles Tammen and Bergendoff to prepare plans for the replacement of the electrical drive and control system. The intervening months were used to prepare plans for the replacement of the electrical system, plans to replace the existing mechanical system when long term reliability of the existing machinery was in doubt. The procurement of the necessary equipment and the removal of the existing and installation of the new system within a short window of opportunity when navigation on this year round waterway could be halted.

This paper will consider the problems encountered, the teamwork approach used to address these problems and the solutions used during the preparation of the plans for the new drive machinery and the successful installation of the machinery and electrical system.

HISTORY

The Burlington Northern Railroad (BNRR) main line from Seattle to Everett, Washington passes over the entrance to the Lake Washington Ship Canal immediately downstream of the Chittendon Locks in the Ballard district in the northern section of Seattle. The tracks span the navigation

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[1]Engineers within the Kansas City office of the firm of Howard Needles Tammen & Bergendoff, Architects, Engineers, Planners

channel by the use of a 200 foot long, double track, single leaf Strauss Heel Trunnion Bascule Bridge constructed in 1921. The total mass to be moved was 2,300 tons. The bridge was still being operated by the original electrical drive and control system because of numerous repairs and "patches" made by the railroads maintenance forces. The existing drive motors were reported to be in poor condition although they had been repaired and rewound several times in the past. It was reported that the firm who had been doing the repairs had indicated that they did not want to see the motors again. The electric drive motors were powering the leaf via the original mechanical system which had also been repaired in the past.

In September ,1990, the Burlington Northern Railroad contacted the firm of Howard Needles Tammen & Bergendoff (HNTB) with a request that plans be prepared for the replacement of the existing electrical drive and control system using a programmable logic controller and an A. C. Flux Vector Variable Frequency Drive system as manufactured by Anderson Electric Company, Seattle, Washington.

As one of the first items of work, the existing bridge was inspected to determine the available space for the new drive system and to develop a sequence of installation and removal which would minimize the time when the bridge would be inoperable. During this site visit, the condition of the existing drive machinery was noted to be in only fair to poor condition with questionable long term reliability. Several factors caused this judgement. One was a missing tooth in the main differential gear, another was several other reduction gear sets showed significant amounts of wear and distressed tooth contact surfaces. In addition, some of the supporting bearings showed evidence of excessive wear in the bronze liners indicating need for replacement and also permitting misalignment of the supported gear sets. Because of the condition of the existing drive gearing, it was concluded that the existing drive machinery should also be replaced and HNTB was requested to also prepare plans for the total replacement of the existing drive machinery except for the racks and rack pinion gears which were in a condition where their continued use was warranted.

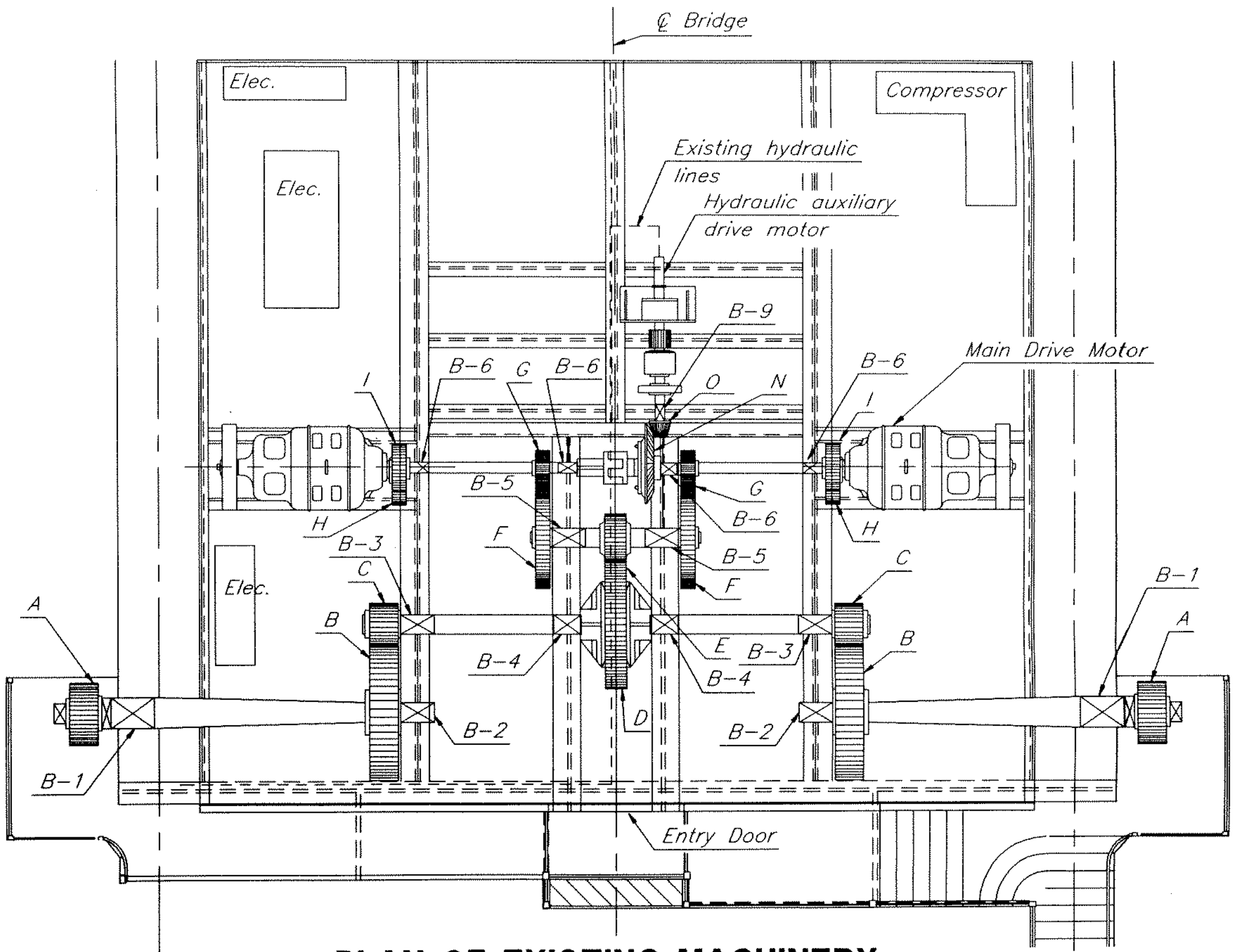
Three machinery replacement options were prepared and presented to the BNRR for consideration and selection for the replacement option. Factors used in the selection were initial cost, time required for field installation, maintenance requirements and access to the equipment. The existing machinery room layout and the layout of the selected replacement option is shown on the following two pages. The machinery alternative selected would permit the fastest installation time and would require the least amount of routine maintenance.

Access to the existing machinery room consisted of a small entry door near the center of the channel wall and window openings in the rear wall of the machinery room. Because of the limited access openings and because the existing roof of the machinery room was in only fair to poor condition, it was requested that HNTB further expand their plan preparation to include the removal of the existing and the installation of a new roof for the machinery room to facilitate the removal of the existing equipment and the installation of the new equipment.

Plan views showing the existing machinery room layout and the final selected alternative machinery room layout is shown on the following two pages.

REPLACEMENT TIME RESTRICTIONS

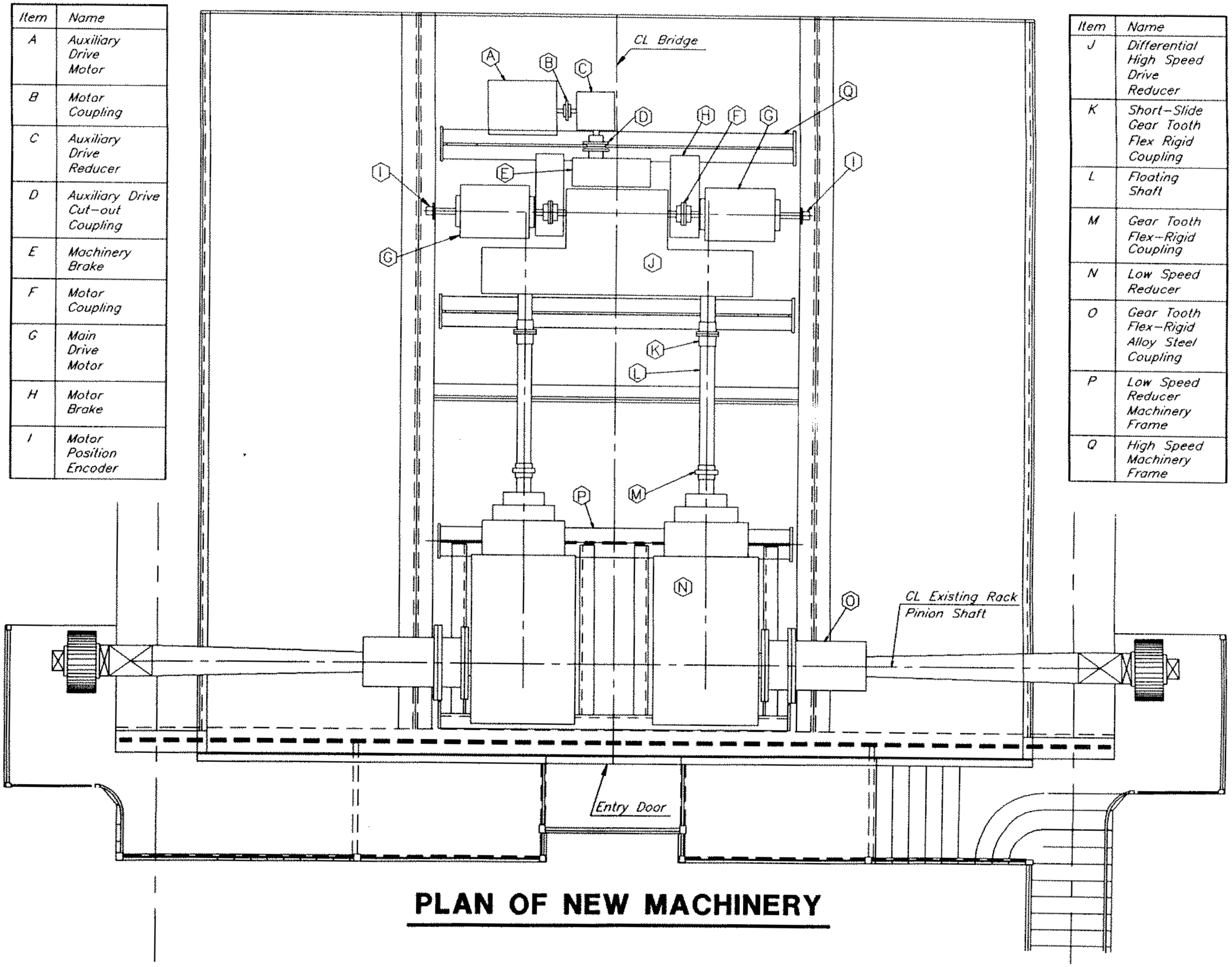
The Lake Washington Ship Canal provides all marine access from Puget Sound to Lake Washington. There is a large amount of marine traffic on this waterway year round including a mixture of pleasure craft and commercial vessels. Obtaining a permit from the United States Coast Guard (USCG) for the interruption of navigation for a significant period of time was considered to be difficult. Compounding the problem of accommodating marine interests was the fact that the railroad did not have a realistically viable detour route for rail traffic. The only available rail detour would have required rerouting traffic on the other side of Lake Washington, a route which would have a significant increase in both rail miles and time delays. It was determined that the Corps of Engineers were going to close the Chittendon Locks for maintenance repairs for a one week time period. It was decided that during this time period, it would be reasonable to close the bridge to marine traffic because no marine traffic had docking facilities between the bridge and the locks. Therefore, the preparation of plans and the procurement of materials had to be scheduled in a short time frame in order to be able to replace the machinery and electrical systems during this time window.



PLAN OF EXISTING MACHINERY

Item	Name
A	Auxiliary Drive Motor
B	Motor Coupling
C	Auxiliary Drive Reducer
D	Auxiliary Drive Cut-out Coupling
E	Machinery Brake
F	Motor Coupling
G	Main Drive Motor
H	Motor Brake
I	Motor Position Encoder

Item	Name
J	Differential High Speed Drive Reducer
K	Short-Slide Gear Tooth Flex Rigid Coupling
L	Floating Shaft
M	Gear Tooth Flex-Rigid Coupling
N	Low Speed Reducer
O	Gear Tooth Flex-Rigid Alloy Steel Coupling
P	Low Speed Reducer Machinery Frame
Q	High Speed Machinery Frame



PLAN OF NEW MACHINERY

EQUIPMENT DESIGN CRITERIA

The drive machinery and electric drive motors were sized using the American Railway Engineering Association (AREA) Specifications for loads and maintaining the time of opening determined by field measurements. Although ice is a rarity at this location, the provisions for the ice loading was included because of the climate conditions. During the winter months, frequent rains permits the timber ties to absorb significant amounts of water and the remaining structure would retain a moisture film. The use of the ice load was used to account for these adverse conditions of operation.

The design plans prepared considered the use of several different manufacturers products being utilized within the machinery and electrical drive systems. These included the Philadelphia Gear Corporation for the design and manufacture of special gear reducers including a special triple input, dual output differential reducer, the Falk Corporation for a special gear tooth flex-rigid coupling as well as standard gear tooth couplings and their Steelflex coupling at the motors, Anderson Electric for the main drive motors and auxiliary drive gear motors, the Mondel Corporation for the furnishing of the brakes and the Ringfeder Corporation for shrink disks to hasten field installation. The limited available space, and the need for minimal installation time required that these manufacturers be consulted with and their input and cooperation is hereby gratefully acknowledged.

The removal of the existing and installation of the new mechanical and electrical system was anticipated to be accomplished by the BNRR using their B & B crews. The design prepared also had to consider the requirements of these persons in order to facilitate installation. Again, consultation with these persons was necessary for the proper design package and their cooperation and input is also hereby gratefully acknowledged.

The teamwork of these many different companies both during the preparation of the design package and during the installation of the equipment resulted in a successful completion of the changeover with a minimum of problems during installation.

DESCRIPTION OF THE ELECTRICAL DRIVE SYSTEM

Teamwork and coordination began with the selection of the main drive system desired by the BNRR. The main drive motors required were A. C. three phase induction, squirrel cage, motors. Because of limited space and motor horsepower requirements, two main drive motors were selected with both being required for adverse loading conditions. The size and installation requirements for the relatively new flux vector drives required immediate coordination with Anderson Electric Co. One of the features required relocation of the motor brakes from being installed on the back of the motors. The flux vector drive required the installation of an encoder at the back of the motor where a brake would normally be installed.

The original drive system had provided for the use of a gasoline drive auxiliary drive system. This system had been abandoned by the BNRR and a hydraulic motor was installed in its place. It was originally intended to retain the hydraulic motor and drive system for use as the auxiliary drive system. This was abandoned during the preparation of the design package in favor of the use of an A.C electric gear motor. Several factors led to this decision including the facts that the diesel engine driving the hydraulic pump would have to be replaced, all of the piping between the pump and motor would have to be replaced due to necessary relocation and due to connection leakage in the very high pressure lines, the cost of a gear increaser to interface with the motor and new machinery system and the cost to provide a complete fluid containment system to protect the environmentally sensitive waterway from any unintentional fluid leaks were also factors considered. Based upon these many factors, it was concluded that the abandonment of the hydraulic system in favor of the electric gear motor would reduce the final installed cost. Consultation and coordination with the BNRR during the development of this decision was a necessary part of this portion of the preparation of the design. Prompt decisions were necessary to maintain critical time schedules.

LOW SPEED REDUCER TO EXISTING PINION SHAFT

The existing racks, rack pinions and rack pinion drive shafts were considered to be in a condition which warranted their salvage and reuse. In order to connect the shaft to the new low speed reducer, the bearing supporting the end of the shaft and also the adjacent gear had to be removed. There was no reasonable location where a new shaft supporting bearing could be installed because the shaft between the drive gear and the rack pinion was tapered, did not have a precisely round section at any location and the time required to provide for and install a bearing would seriously inhibit the installation of the machinery within the required time period. It was decided that no external bearing would be provided to support the pinion shaft. Rather, a gear type flex-rigid coupling would be used to connect the shaft to the low speed shaft of the reducer and the reducer bearings would be sized to provide the additional capacity to support the shaft and its impressed loads.

The existing pinion shaft bearing being abandoned was immediately above the longitudinal machinery room and machinery support beam with the drive gear mounted immediately outboard of the bearing. The journal diameter of the shaft at the bearing was insufficient to transmit the required torque in the shaft, hence, attachment at this location could not be used. The shaft diameter at the existing gear had been transmitting the required torque so it was concluded that the gear coupling would have to be installed at this location.

Coordination and consultation with Philadelphia Gear Corporation and the Falk Corporation was necessary to provide for the best solution to making this connection. Several factors had to be addressed prior to finalizing the details at the coupling connection. One option was to cut off the bearing journal shaft of the pinion shaft in the field and extend the reducer shaft to permit the installation of a standard gear coupling. The other option was to leave the bearing journal shaft in place and provide a special long rigid hub on the coupling. Cutting off the shaft in the field would take critical time. Extending the low speed reducer shaft would increase the overhung load on the reducer bearings. Providing a special extended rigid hub to span the bearing journal to reach the gear journal would increase the cost of this large coupling. The available width for the low speed reducer was limited because the only access to the machinery room was through a door in the front wall and an aisle way between the two low speed reducers. The distance from the pinion shaft to the top of the machinery support beam limited the outside diameter available for the coupling. Cutting off the shaft and using a standard coupling would reduce the cost of the coupling but would increase the cost of the reducer. Compounding this economic decision was the time required to cut off the shaft journals in the field considering the total available time. A further complication which had to be addressed was the high radial load which had to be transmitted by the gear coupling.

The Falk Corporation made their recommendation on the size of coupling necessary to transmit both the torque and radial load. After further consultation, it was determined that the recommended size could be used if the outside diameter was slightly reduced so that it would clear the machinery support beam. The Philadelphia Gear Corporation was being consulted at the same time. The procurement costs for the low speed reducers were evaluated for both conditions of a standard low speed shaft extension and the increased shaft extension for mounting the two coupling options. After several telephone calls to both the Falk Corporation and Philadelphia Gear to make sure that all necessary parameters were understood by all parties, the mutual decision was reached that the Falk Corporation would provide the special long rigid coupling half for their coupling so that Philadelphia Gear could use a standard shaft extension on their gear reducer.

ATTACHMENT OF LOW SPEED COUPLING TO THE EXISTING SHAFT

According the information in the available plans, the gear being removed to permit the installation of the special low speed flex-rigid gear coupling had been mounted to the shaft journal with two keys used to transmit the necessary design torque. If both of these keys were retained for torque transmission, field installation by shrink fitting the coupling to the shaft would be extremely difficult, time consuming and somewhat more dangerous because of having to handle the heated coupling.

It was felt that the alternative to traditional methods should be explored and the use of shrink disks could be a viable alternative to heat shrinking. Discussions were held with the Falk Corporation and the Ringfeder Corporation on the desirability of providing for an external sleeve type shrink disk on the coupling to provide the clamping force between the coupling hub and the existing shaft. The Ringfeder Corporation made recommendations for the size and type of shrink disk required in combination with the requirements of the Falk Corporation for the necessary hub thickness between the shrink disk and the shaft. These discussions included the decision to retain one of the keys in the existing shaft, for insurance purposes, and to fill the remaining keyway in the existing shaft.

After it was determined that it was felt that each of the parties understood all of the requirements for the installation using shrink disks, the recommendations of both parties were incorporated in the design plans. The costs to provide this installation compared very favorably with the costs estimated for the heat shrinking options without the inherent difficulties of field heat shrinking this large coupling.

HIGH SPEED REDUCER

Because of the required layout of the low speed reducers, the connection from these reducers to the main and auxiliary drive system caused additional difficulties. No standard reducer would accommodate the requirements for this high speed reducer. Again several options existed and coordination with Philadelphia Gear began in order to arrive at the best solution. One option was to use three separate standard reducers. Two of the three would be right angle reducers aligned with the low speed reducer input shafts and the third reducer located midway between them to provide an initial differential reduction and the desired input shafts for the main drive motor and the auxiliary drive system. The other option was to take the general features of these three reducers and combine them into one special reducer. After consideration of the relative cost of the options, including design and fabrication of the units and the cost of installation of the units on their supporting frame, it was concluded and agreed that one special unit would be provided.

REDUCER LUBRICATION PROVISIONS

The enclosed reducers could be properly lubricated with more than one type of lubricant. Again coordination with several parties was undertaken to provide the best solution for the purpose. An oil lubricant was to be specified however the options of a petroleum based oil or the use of a synthetic oil had to be determined. The solution was found after discussions with BNRR and Philadelphia Gear personnel. The petroleum based lubricant would have a much lower initial cost. The synthetic lubricant should have a much longer service life between oil changes thus reducing maintenance costs. Synthetic oils require better and more expensive seals in the reducer to prevent leakage. It was concluded and agreed to by all parties that the reducers should be provided with the more expensive synthetic oils initially in order to reduce the long term maintenance costs. Philadelphia Gear indicated and provided assurance that the seals in the reducers would be capable of retaining the oil without leakage with the oil level being established above the top of the gearing within the reducers. Again, coordination with the owner, the design engineer and the reducer manufacturer resulted in the most desirable solution considering the projected long term costs to the owner.

REDUCER SUPPORT FRAMES

After determining solutions to the design and manufacturing requirements for the machinery reducers for the replacement of the mechanical drive train, the remaining decisions to be reached regarded the machinery supporting frames.

As discussed previously, there was a limited time available to remove the existing drive machinery and to install the new machinery drive system. It is immediately apparent that the fewer drive elements which had to be aligned and installed in the field, the less time would be required to effect the installation. The existing machinery house is located above track level within the tower framing of the Strauss Heel Trunnion Bascule Bridge. The existing bridge carries two tracks for rail service and it was desired that at least one of the tracks be open for rail service throughout the time period when the machinery was being replaced. Thus the desire to reduce the installation time by reducing the number of elements to be installed had to be balanced by the ability of providing equipment with the lifting capacity to hoist the equipment into the machinery room. A further complication would be the ability to make precise alignment adjustments of heavy components once within the machinery room.

Meetings were held and site visits were made by members of the BNRR installation crew, HNTB, Everett Engineering[2] and crane rental representatives. Lifting weights were determined for the individual reducer elements were obtained from Philadelphia Gear. It was determined that the two low speed reducers could be mounted on a common frame and could be hoisted and adjusted as one piece in the field. A similar conclusion was reached for the high speed reducer, the reducer, brakes, main drive motors and auxiliary drive system could be mounted on a common frame for installation in the field. Thus, after the necessary coordination and

[2]Everett Engineering was a firm of machinists and millwrights being retained by the BNRR to provide assistance in the installation of the equipment and any final machining of equipment required during the installation period. One specific item requiring machining was the Falk low speed coupling being mounted on the existing drive shaft which could not have its final bore machined until after the removal of the existing drive gear and the shaft journal diameter determined.

agreement of the installation procedure, the final design of the machinery supporting frames could begin.

Because of time constraints, the BNRR reached an agreement with and provided a purchase order with Philadelphia Gear to provide the new reducer packages. Thus, coordination could begin to design the machinery support frames around the actual reducer being provided. This permitted a more exact requirement for the frame and would permit the proper coordination with the reducer manufacturer to provide design requirements for the support based upon an agreed to footprint of the reducer. This was more important for this project than normal because of the limited space within the existing machinery room. The machinery had to fit between the two existing machinery support beams and also had to fit between the floor of the room and the level of the centerline of the existing machinery. The physical restraints prevented the main support beams from being located below the bottom of the reducers and special mounting supports located to the side of the reducers had to be provided.

As can be seen, in order to provide for the proper supports to the reducers, coordination and agreements had to occur with the parties installing the equipment, the company providing the machinery reducers, and the design team providing the plans for the support frames.

SEQUENCE OF CONSTRUCTION

As discussed previously, the installation time was extremely limited. Because of this, a detailed sequence of construction was developed as a part of the design plans. The sequence of construction developed had to include the necessary work both prior to and during the installation process. Although the installation process was critical, the necessary work prior to this period was just as critical. If the necessary work prior to installation was not completed, it would impact the time available during the installation process. The sequence further defined the party responsible for the completion of the individual tasks within the sequence.

An initial detailed sequence of construction was developed and distributed to interested parties. After time for their review, a meeting was held with all affected parties in attendance to both discuss, and receive comments and suggestions for accommodating each party's individual requirements. Time requirements and the sequence for both completeness and assignment of duties was discussed. The meeting produced several suggestions and resulted in some changes to the sequence. The meeting further emphasized the necessity for each party to be aware of the full extent of the work and to provide them a forum for them to detail their requirements where further coordination of various parties was needed.

After the initial meeting, the sequence was revised to reflect the further requirements and suggestions received. After the revised sequence was completed, it was again distributed. Another meeting resulted with additional comments and suggestions not received at the initial meeting. It was felt that the prior planning which resulted from the development of the sequence of construction and the joint meetings held to discuss the sequence had a lot to do with the successful installation later because all parties were thoroughly prepared and had undertaken tasks necessary to prepare for the critical installation process.

After the sequence of construction was completed, a detailed sequence with time allotments added was prepared for the period when the actual removal of the existing and installation of the new equipment was being undertaken. The same process of preparation, review and joint meetings was used for the final preparation of this critical timed sequence of construction. As with the earlier sequence, responsible parties were assigned to each task.

As you are probably aware, disruption of navigation requires the approval of the United States Coast Guard. The BNRR had several discussions with the USCG during the development of the replacement plans. The detailed timed sequence of construction developed was part of the documents provided to the USCG as a part of the basis for the request for the necessary time. It is our understanding that this document provided valuable documentation to the USCG as to the necessity of the time requirements being requested.

COORDINATION OF WORK EFFORTS

The BNRR had contracted with Philadelphia Gear Corporation for the procurement of the new drive machinery and machinery support frames and with Anderson Electric Company for the procurement of the complete electrical system based upon the design plans and specifications prepared by HNTB. During the time when these two items were being assembled and fabricated, the BNRR began installation of field electrical wiring, the preparation of the machinery room for the installation of the new machinery.

The available time after procurement began and the time when installation had to begin was very limited and further required coordination between the BNRR, Philadelphia Gear and Anderson Electric. One example of required coordination was that Anderson Electric had to procure the main drive motors, make necessary modifications for attachment of the encoders to the end of their shafts and make necessary tests of operations with the control system and then ship the motors to Philadelphia Gear. Philadelphia Gear then had to mount the motor couplings and mount the motors to the reducer frames for shipment to the job site. All of this work had to be accomplished in order for the BNRR to have sufficient time to provide for shipment of the completed packages to the job site.

The BNRR requested that HNTB provide coordination services for the project. Coordination included the authority to act as their agents and contact all parties, including BNRR installation personnel, directly as required to maintain the established schedule. Records of telephone calls and all correspondence were copied to the BNRR for their information.

It is considered a credit to all parties and suppliers involved that the required equipment all reached the job site on time and that the job site preparations made by BNRR B & B personnel was completed in time for the scheduled installation period. The complete cooperation by the BNRR, Philadelphia Gear, Anderson Electric, Falk, Ringfeder and Mondel was necessary in order to maintain the established schedule. The schedule was very tight and restrictive because of the scheduled time to coordinate the installation during the time when the adjacent locks were out of service.

CONSTRUCTION PHASE

Planning and the communication developed throughout the design and fabrication phases peaked during the weeks prior to and during the change out of the existing equipment. The details that were remaining to successfully complete the project were numerous and critical. Just one could greatly effect the outcome and the critical time required to complete the installation prior to Easter Sunday. Critical items included the shipping of the machinery, the installation of the electrical distribution system, the installation of the new incoming utility service, receiving a new emergency generator, temporary electrical service for the bridge, installation of temporary electrical service for lighting and convenience outlets to permit a 24 hour a day schedule and protection of the numerous railroad and non railroad personnel that would be on the structure at all hours of the day and night.

An example of one activity that occurred within the week prior to the change out was a conference call between the BNRR, the USCG, Everett Engineering, U.S. Army Corps of Engineers, the Contractor working on the Locks and HNTB. With less than a week to go prior to the scheduled and published navigation closure , a request was made to delay the start of our closure from the Coast Guard of at least 12 hours. This was to allow a special crane operating at the locks to return through the bridge prior to the closure, otherwise, they would be forced to wait for the bridge to reopen a week later. The issues were evaluated and the BNRR agreed to delay the start of the equipment removal by 24 hours to accommodate the lock work. The U.S. Coast Guard agreed to allow the BNRR to have an additional 24 hours added to the published schedule. With Easter being on the following Sunday, this was considered critical to schedule. Arrangements had to be made with the workers, suppliers etc. to provide equipment, parts supplies and tools to handle any reasonable anticipated need during the closure activity. Once the removal of the existing equipment began the bridge would not be operable until the new equipment was in place and connected. The companies working and involved were also required to work on a 24 hour day basis until the bridge was restored to service.

Equipment, as it was received, was checked and rechecked to determine if all constraints had been discovered, what changes, if any, existed and what effect that they would have on the installation. Numerous concerns were discovered and uncovered during the few remaining days prior to the installation. Due to the extreme cooperative efforts of all the parties none of these items delayed the beginning or end of installation. The most significant of these items was the discovery that the existing machinery floor was not nearly as level as was originally thought. During the design and fabrication phases the existing concrete floor was hidden from view by a wooden walkway installed above the existing floor. After the wood had been removed and the existing floor was cleaned, it was discovered that the machinery floor varied in height by over 3 inches in some places. With clearances being minimal the discovery of a potential interference was of concern. This could significantly reduce the available alignment tolerances to install and align the low speed reducer assembly already on the site. Discussions with the BNRR, Everett Engineering and HNTB determined that a combination of items could eliminate the installation difficulties and remedial action was taken. On Friday April 10, 1992 the machinery frame was sent to Everett Engineering's shop to have shims between the low speed reducer and the reducer frame removed and frames modified effectively raising the frame to adjust for the effect of the existing floor. In addition portions of the existing floor would be chipped slightly to give the maximum clearance believed necessary at the time of installation. The reducer frame assembly was to be picked up on Monday and returned to the job site.

Final preparation work was completed on Monday for the impending closure with all parties confident that whatever could have been anticipated had been and the machinery removal was to begin the following morning. Closure began on schedule with little fanfare, just 20 plus workers scrambling for a place to work and attempting to find a location for the equipment they had brought. By late afternoon the existing machinery had been removed and the existing floor was being prepared for the new equipment. Workers were busily preparing the existing supports for the arrival of the new machinery.

At dark on Tuesday the high speed reducer and frame with its factory furnished custom lifting frame tested the BNRR track crane and was lifted almost with out incident into the machinery room. The equipment was rolled to is final location on Hillman Rollers because interference from the existing structural steel supporting the span and the counterweight truss frames prevented the crane from placing the frame at its final location.

The final machining for the special low speed coupling was ongoing as the day became Wednesday. The high speed frame sat in the rear of the machinery room awaiting the low speed reducer frame. Work was progressing on the remodeling required for the existing supports to accept the new equipment. The couplings and the special shrink disks by Ringfeder were readied for installation by mid morning. A field service engineer from Ringfeder assisted the BNRR with the installation. The Ringfeder disks couplings were placed and tightened by late afternoon and the low speed reducer frame and custom lifting assembly was readied for installation in the machinery room.

The existing shafts had also been determined to be out of line with each other. Due to the age of the equipment and the presently worn in condition of the rack and rack pinion, it was determined not to change the present alignment of the shafts but to align the new reducers to the existing shafts. Again modification to the alignment of a low speed reducer to the machinery frames was required to continue the installation.

Due to the high loads impressed upon the special low speed couplings it was decided that the alignment of the low speed coupling would be set such as to provide for minimal misalignments and to take the remaining known misalignment in the floating shafts between the high speed and low speed reducers. Conversations between Philadelphia Gear, the Falk Corporation, Ringfeder, HNTB and the BNRR resulted in concurrence on this decision thus minimizing the required installation time and achieved the best alignment considerations possible between the existing and new equipment.

Progress slowed as the installation of the low speed reducers continued into and throughout Thursday. Other work progressed concurrently including completing the electrical connections to the new motors, brakes and position and limit switches recently installed. Testing of the electrical circuits was performed prior to the installation of the machinery floating shafts between the reducers. This insured proper operation and minimized the staff of electrical installation personnel required in the existing machinery area's confined location during other critical times. Even with some short tempered exchanges caused by, working long hours, deteriorating weather conditions and a few undesired complications the work sped toward completion.

The project staff caught its second wind by Friday as the progress of the work accelerated with the completion of the low speed reducer installation. The work now focused on the installation and the alignment of the high speed reducer assembly. The project had rid itself of Murphy's Law and by the early morning hours of Saturday the installation was nearly complete. The cleanup of the fast paced few day began with a sense of accomplishment. At 7:30 A.M. a test lift of a few degrees was made to see how the electrical system operated with the new machinery for the first time The machinery operated as designed with out effort and so quiet that you could not even tell that the bridge was operating if you were not looking at it.(a substantial change from the operation of the existing equipment). We watched with excitement as the first full lift of the bridge was made at 8:00 A.M. busily checking all of the parts for clearance and proper operation. We retired from the project briefly to enjoy breakfast together sharing our efforts, cooperation and friendships as we watched the bridge in the background.

The bridge operation was tested throughout the morning and the USCG was officially notified at Noon on Saturday April 18, that the bridge was fully operational. It should be noted that the bridge was operated for several vessels prior to the official opening at Noon. As the local boaters became aware of the bridge being operational the vessels returned to the bridge to pass to and from the Puget Sound.

After this installation, the bridge was operational by the use of the auxiliary drive system only. Early during the design process, it was decided that this critical installation period should focus on the replacement of the machinery and making the bridge operational on the auxiliary drive system. It was decided at that time to defer operations with the main drive motors until a later date when this work could proceed at a more normal pace and off of the critical installation path.

An additional effort was completed in July as the Programmable Controller and the Flux Vector Drive system was tested, debugged and made operational in a short two and one half day time period. The bridge is currently operating on the main drive system (the Flux Vector Drives) with the auxiliary drive system available should it be required to operate the bridge.