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"Conversion of a Railroad, Center Pivot Swing Span to Rim Bearing Under Traffic"

by

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CONVERSION OF A RAILROAD CENTER PIVOT SWING SPAN TO RIM BEARING UNDER TRAFFIC

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INTRODUCTION

HNTB in partnership with the Burlington Northern Santa Fe Railroad (BNSF) have completed a major renovation to a 77-year old single track, 260-foot long center pivot swing span. The BNSF Railroad Bridge 37.0 is located in Everett, Washington over the Snohomish River. This bridge is located on a major North-South route between the Port of Seattle and Canada. This portion of the project was the final phase of a three phase, five year total mechanical and electrical system replacement. The Phase III completion was highlighted by the replacement of the main drive turning machinery and the installation of a horizontal load supporting bearing rim placed around the center pivot pier. All steel construction and equipment installation was performed by BNSF Bridge and Building personnel while the bridge remained under rail traffic.

The objective of this paper is to inform the reader of the key elements involved in the design of this unique solution for Phase III of this project. This paper will discuss the design constraints encountered, the design methods followed, and the construction sequencing to complete the rehabilitation of BNSF Bridge 37.0.

HISTORY

Bridge 37.0 was originally constructed in 1921 and is a unique structure due to several design features built in by the Great Northern Railroad, now the BNSF. This bridge was the tenth structure to the Northeast of Seattle and is one of six similar swing spans on this line. Bridge 37.0 is the only bridge of the immediate nearby four to have end lifts, the other bridges all have end wedges. Bridge 37.0 was also the only bridge to have the end lifts, center wedges and rail joints operated by pneumatic power. The extensive maintenance requirements of the pneumatic power system was the primary reason for the rehabilitation. BNSF estimates that the pneumatic maintenance over the last several years ranged from $250,000 to $300,000 per year. These maintenance costs became a constant requirement that was budgeted into the Northwest operations maintenance department annual budget. The method of operation became so practiced that it was considered normal maintenance and no long term solutions were discussed for nearly 20 years.

Bridge 37.0 has since had several center pivot bearing repairs and replacements. Repairs to the rack and rack pinion became more frequent, but were considered minor and no reason for concern. Therefore, funds for rehabilitation were allocated to other more serious problems. In the late 1980's a pneumatic hose operating the end lift mechanism ruptured as a train crossed the bridge. The end lift collapsed causing the rail joint's easer bars to pierce the passing train, consequently derailing the train on the bridge. The derailment caused minor structural damage to the bridge, but closed the span to navigation for nearly one week. This derailment and subsequent operating failures over the next several months caused the Burlington Northern Railroad (BN), now the BNSF, to focus attention towards the old operating system. The BN considered numerous operating system solutions such as pneumatics, hydraulics, and machinery. HNTB was hired to investigate and evaluate several of these options and make recommendations to assist the BN in the planned repairs.

INSPECTION

HNTB conducted an inspection of the bridge to determine the cause of the operational malfunctions on Bridge 37.0. It was determined that the horizontal forces subjected to the span were being transferred to the twin rack pinion vertical shafts and consequently into the rack gear. The vertical rack pinion shafts, rack gear, and rack gear anchorage system were not designed to carry horizontal loads. This increased horizontal load transfer into the rack gear caused extensive damage to the rack gear anchorage system. Years of high horizontal loading have caused the rack gear to become out-of-round. It was determined through a comparison between the wind forces on the span and the existing rack pinion bearing bolt and rack gear anchorage bolt allowable strengths, that the wind forces were greater than the existing bolts' allowable strengths. The greater wind forces caused the rack pinion bearing bolts and rack gear anchor bolts to break, allowing the span to shift into an elliptical rotating pattern during operation. This out-of-round or elliptical shaped rack gear caused the rack pinion to disengage the rack gear several times.

The center pivot bearing was primarily designed as the horizontal load transfer mechanism between the bridge and the pivot pier. Through further inspection of the center pivot bearing it was determined that the bearing was undersized to successfully transfer the horizontal loads from the bridge to the pivot pier. The existing center pivot bearing is not the original bearing of the structure. BNSF records indicate that the center pivot bearing had been replaced in-kind in 1928 and again in 1948. The inspection determined that the center pivot bearing housing was not damaged, but the internal bronze bearing lenses have worn elliptical groove patterns in each lens face. This elliptical travel pattern caused the span to not rotate back to the original starting position, which caused end lift malfunctions and rail joint misalignments. The shifting of the span consequently caused damage and irregular wear to the existing turning machinery shafts, bearings, and open gearing. This machinery damage was evident during operation by the loud grinding sounds made by the open gearing.

The existing center pivot bearing is only 18" tall and located such that replacement of the assembly under rail traffic would not be a feasible solution, nor would the United States Coast Guard (USCG) grant an extended navigation closure for the lengthy replacement. Therefore, a solution was developed in which a device would be designed to hold the span in a circular position during operation.

SOLUTION

The solution was to retain the existing center pivot bearing as only a vertical load carrying device and install an outer rim bearing system to provide for all horizontal loads. This rim bearing system would carry all horizontal loads being transferred from the bridge to the pivot pier through four vertical shaft mounted rollers. The installation of the rim and rollers would enable the span to rotate in a circle without having to replace the center pivot bearing; the installation would also allow for vertical movement as the center pivot bearing lenses continue to wear. This solution better incorporated the removal of the existing turning machinery and installation of the new turning machinery, rack pinions, and rack gear. This solution provided for construction under rail traffic with a minimal seven day navigation closure.

Phase III rehabilitation included replacement of the main drive turning machinery and the center wedge drive machinery. The following installations were also included in Phase III rehabilitation: a new horizontal force carrying rim around the outside of the pivot pier, a new rack gear, four new horizontal rollers, and new structural bearing support beams to brace the new rack pinion and horizontal roller bearings. Phase III rehabilitation also included the construction of a new control house located on top of the swing span in the center of the bridge. This new control house is larger than the existing control house, sized to include the electrical equipment, and be more comfortable for the operator. The control house included a new control console and a new programmable logic control system which would control all bridge mechanical operating systems.

Two phases of rehabilitation were completed prior to Phase III. Phase I completed the interfacing of new temporary electrical controls necessary to control the new end lifts and rail joints operating machinery with the existing control system. Phase II completed a mechanical rehabilitation to the end lift mechanisms at each end of the bridge. The existing pneumatic drive cylinders were removed and a new electric gear motor was installed at each end of the span. Phase II also completed a mechanical replacement of the existing rail joints' easer bars operating equipment by installing new easer bars, a new electric gear motor, and a new crank shaft at each end of the span. The existing air tanks were removed and a new air compressor was installed in a new building built on the span to operate the existing center wedges. This phase also included providing new grating and handrail for the full length of the span. These previous phases were implemented first to help decrease the end lift and rail lock misalignments until the Phase III rehabilitation could be completed.

DESIGN

The design effort for Phase III was broken down into two major parts. Part one designed the mechanical operating systems. Part two designed the structural supports for the machinery components designed in part one. The design of all components in this project were designed in accordance to AREA Manual for Railway Engineering Chapter 15. This design work and detailing was completed by HNTB as the prime consultant to the BNSF.

A machinery schedule sheet was provided in the plan details that labeled and described each piece of the following operating machinery. The mechanical design work included the following design steps:

1. Main Drive Turning Machinery - - Two sets of turning machinery are required to operate the span. Each main drive consists of a 10 HP, two-speed, constant torque motor which drives a quadruple reduction right angle gear box. The low speed reducer shaft is supported by a new pillow block mounted spherical roller bearing and operates the new cantilevered rack pinion. Each set of turning machinery also has an in-line set of auxiliary drive machinery. Each auxiliary drive consists of a 5 HP single speed gear motor that is activated by an electrically engaged clutch. Each set of main drive and auxiliary drive turning machinery is located in the center of the bridge between the stringers. The span operates in 2 minutes and 30 seconds using the main drive motors and in 4 minutes and 30 seconds using the auxiliary drive motors. See Figures 1 and 2 for detailed plan and elevation views of the main drive and auxiliary drive turning machinery.

2. Center Wedge Drive Machinery - - Two sets of center wedge drive machinery are required to operate the center wedges, one set of machinery for each wedge. Each center wedge drive consists of a 5 HP wafer thin motor which drives a quadruple reduction right angle gear box. The low speed reducer shaft is supported by a new pillow block mounted spherical roller bearing and operates a new bevel pinion. Each set of center wedge drive machinery is located in the center of the span between the two center floor beams. The center wedges operate in approximately 20 seconds and are both operated simultaneously. See Figures 1 and 3 for detailed plan and elevation views of the center wedge drive machinery.

3. Span Position Equipment - - The new span position equipment is used in conjunction with physical span limit switches to maintain proper span speed and span position during operation. Two sets of span position equipment are required, one for each set of main drive turning machinery. Each set of span position equipment is located on top of each main drive reduction gear box. The span position equipment is attached to the first set of reduction gearing in the main drive reduction gear box and consists of a series of small reduction boxes with a position resolver at the end. The position resolver counts the revolutions made by the first set of main drive reduction gearing. The continual count of revolutions is relayed to the position encoder located in the control house. This position encoder translates the number of revolutions into the number of degrees the spans position is in and displays the number on a digital readout located on the control console. See Figure 2 for a detailed elevation view of the span position equipment.

4. Rack Pinion and Rack Gear - - There are two rack pinions, one dually keyed to each low speed reducer shaft. Each rack pinion is comprised of 17-20° involute machine cut full depth gear teeth on a pitch diameter of 19.428" with a face width of 7". The

rack gear is comprised of 12-30° internal rack gear segments on a 12'-6 3/4" pitch radius. Four rack segments were provided without gear teeth in the areas of no rack pinion travel. Eight internal rack segments were each provided with 22-20° involute machine cut full depth gear teeth with a face width 7 1/2". Each rack gear segment was anchored to top flange of the horizontal rim bearing segments with nine 1 1/4" diameter turned anchor bolts. The rack gear segment end faces were pinned together by two flanged finished pins which fit into two finished slots at each rack gear interface.

5. Horizontal Rollers - - The horizontal rollers were designed to be used in combination with the horizontal bearing rim to hold the span in a circle during operation. Four vertical shaft horizontal rollers were mounted to the span and designed to keep the bridge rotating in a circle around the horizontal load carrying rim. One roller was located in each quadrant of the pivot pier. As the span rotates the rollers would contact the horizontal bearing rim if the span began to rotate out of its intended circular path. The wind force analysis determined that the bridge was being subjected to approximately 98.5 kips of wind force. Each horizontal roller was designed to support a load of 100 kips. The horizontal roller assembly was designed with an 18" diameter steel wheel on a 9" diameter steel shaft. The assembly was supported by one vertical load carrying spherical roller bearing mounted at the top of the shaft and by one horizontal load carrying bronze sleeve bearing mounted near the horizontal roller wheel. The horizontal rollers were mounted to bearing support beams so as to leave at least a gap of 1/8" to 3/8" between the horizontal roller wheel and the horizontal rim bearing surface. See Figures 1 and 4 for detailed plan and elevation views of the horizontal roller locations.

The structural steel machinery support design drawings were detailed as shop drawings so the steel fabricator had minimal problems fabricating the pieces required. The structural design work included the following design steps:

1. Horizontal Rim Bearing Support - - Due to the movement of the existing rack segments, a vertical and horizontal method of anchorage was designed to ensure proper anchoring of the rim segments to the pivot pier. The rim segments were also designed to support the new internal rack segments as well as provided a bearing surface for the horizontal rollers to bear against. See Figure 5 for a complete cross-sectional view of the horizontal rim bearing support. Due to the low steel dimensional constraint, the external rim around the pivot pier where the horizontal rim was to be placed had to be reworked. Approximately four inches of concrete was chipped away from the top and side face of the pivot pier. Also, the existing rack gear teeth were cut away to make room for the new rack pinion to travel. The existing balance wheel track remained in place.

   The horizontal bearing rim comprised of 12-30° steel segments which were fabricated in a 13'-4" radius. Each rim segment was anchored to the existing pier by three vertical 1 1/4" diameter Hilti HVA Adhesive anchor bolts and by four horizontal 1" diameter Hilti HVA Adhesive anchor bolts. Each rim segment also included a 5" x 12" shear key, along with six 7/8" diameter shear studs as part of the rim anchorage system.

The rim segments were centered on the pivot pier by performing a survey to locate the center of the pier. The rim is supported by approximately a 2" high strength grout pad which was poured after placement of the segments was complete. The rim segment end faces are connected together by six 3/4" diameter high strength bolts. The rack gear segments are supported by the top flange of the rim segments with the rack gear segment joints offset from the rim segment joints to ensure a homogeneous structural unit. The rim segments were pre-assembled offsite to match mark the segments for ease during installation. The rim segments measured a maximum of only ±0.003" out of round.

2. Reducer Support Frame - - Due to space constraints between the stringers and the dimensional constraint between the pivot pier and low steel, it was determined that the best way to support the main drive turning machinery reducer was to hang it from steel ties mounted to the top flanges of the stringers. Each reducer support frame consists of two fabricated WT16.5x70.5 beams which run parallel to the reducer. Two 12' fabricated steel ties are mounted perpendicular to the WT16.5x70.5 beams and are supported by the top flanges of the stringers. The steel ties were designed shallow enough as not to support any rail load and subject the machinery to any rail live loading. The reducer mounting frame was modified by the manufacturer to incorporate this method of support. The main drive motor was scoop mounted to the back of the reducer. See Figures 2 and 4 for cross-sectional views of the reducer support frame.

3. Center Wedge Reducer Support - - Each center wedge reducer is supported by two MC12x31 channels which are mounted into the truss chord gusset plate and an existing C12x25 channel. The low speed shaft pinion bearing is mounted to the existing C12x25 channel web. The center wedge drive motor is supported by a WT7x34 mounted between the two new MC12x31 channels. Due to space constraints, the existing I24x79.9 stub stringer beam between the two central floor beams was replaced with a new W16x100 beam. This additional space enabled the new center wedge reducer to be placed in its current location. See Figures 1 and 3 for detailed plan and elevation views of the center wedge drive machinery.

4. Horizontal Roller and Rack Pinion Support Beam - - Each bearing support beam is composed of a single web with top, bottom, and center flanges. Three semi-circle cutouts are made in the web at the center flange location. Two bearing support beams are required, one for each set of main drive turning machinery. Each beam is 5'-8" deep x 19' long and spans across the bridge from truss chord to truss chord. Each bearing support beam is located under each set of main drive turning machinery.

Each bearing support beam is connected to the bottom flanges of the stringers and the bottom truss chord channel flanges. Each bearing support beam is mounted to the bridge with 88 high strength bolts. The drive pinion bearing is placed through the middle semi-circle cutout and is mounted on the center flange of the bearing support beam. The bottom bearings of the horizontal rollers are placed through the outside semi-circle cutouts and are mounted on the center flange of the bearing support beam. The top bearings of the horizontal rollers are mounted to an additional bearing support beam attached to the top flanges of the truss chord channels and the web of the stringers. Additional lateral bracing beams were installed at each horizontal roller location. See Figure 1 for a detailed plan view of the bearing support beam.

CONSTRUCTION SEQUENCE

The BNSF Bridge and Building personnel completed all the steel assembly and machinery installation. Three separate contractors were used during the Phase III project: David Evans & Associates performed the center location surveying of the pivot pier, Osmose Railroad Division assisted in forming and pouring the grout pad under the horizontal rim segments, and Everett Engineering assisted in the alignment of the operating machinery. HNTB conducted the project coordination, provided interfacing of the contractors with the BNSF crews, and provided on-site engineering services for the duration of Phase III construction.

Preparation work prior to the navigation closure included: installation of the new control house and new control equipment, removal of the existing South main drive turning machinery, installation of machinery and horizontal roller structural steel supports, installation of machinery access platforms, installation of the center wedge drive machinery, removal of existing pivot pier concrete for the horizontal bearing rim, placement of 240 degrees of horizontal bearing rim segments, and the placement of the new South main drive turning machinery.

The navigation closure permit was obtained from the USCG for a seven day period over the first weekend in October, 1997. Rail operation was interrupted for ten days during the navigation closure from approximately 9:00 am to 6:00 pm each day, with rail operations resuming during the night hours. During the navigation closure and rail traffic interruption windows, installation of the North and South main drive turning machinery was performed. Several key steps to this process included: installation of the remaining horizontal bearing rim segments, pouring the high strength grout pad under the horizontal bearing rim segments, installation of the internal rack gear, removal of the existing North main drive turning machinery, installation of machinery and horizontal roller structural steel supports, installation of additional machinery access platforms, installation of the four horizontal rollers, and final alignment of the new main drive turning machinery.

The construction was completed on schedule and without delays. The bridge was opened by the new control system and operating machinery as scheduled. Post-navigation closure work performed included site clean-up, installation of final platforms and machinery access ladders, removal of the existing control house, debugging of the operating control system, and operation observation.

CURRENT OPERATION

The BNSF Railroad Bridge 37.0 has been in operation for one year and has experienced no rail delays or navigation delays. The new main drive turning machinery and center wedge drive machinery performs as designed and operates without noise. The horizontal rollers and horizontal bearing rim function as designed and provide the bridge a way to rotate in a circular pattern. The bridge now operates smoothly and without hesitations.

CONCLUSION

The Phase III major rehabilitation of BNSF Railroad Bridge 37.0 was a success. The success of this project is due to the efforts of several dedicated individuals of the BNSF and HNTB. Close communication and a willingness to work together towards a common goal helped create this unique solution. The rehabilitation of BNSF Railroad Bridge 37.0 is a culmination of many phases of construction over several years. The conclusion to this project is that any problem can be solved with good engineering and proper plan implementation.

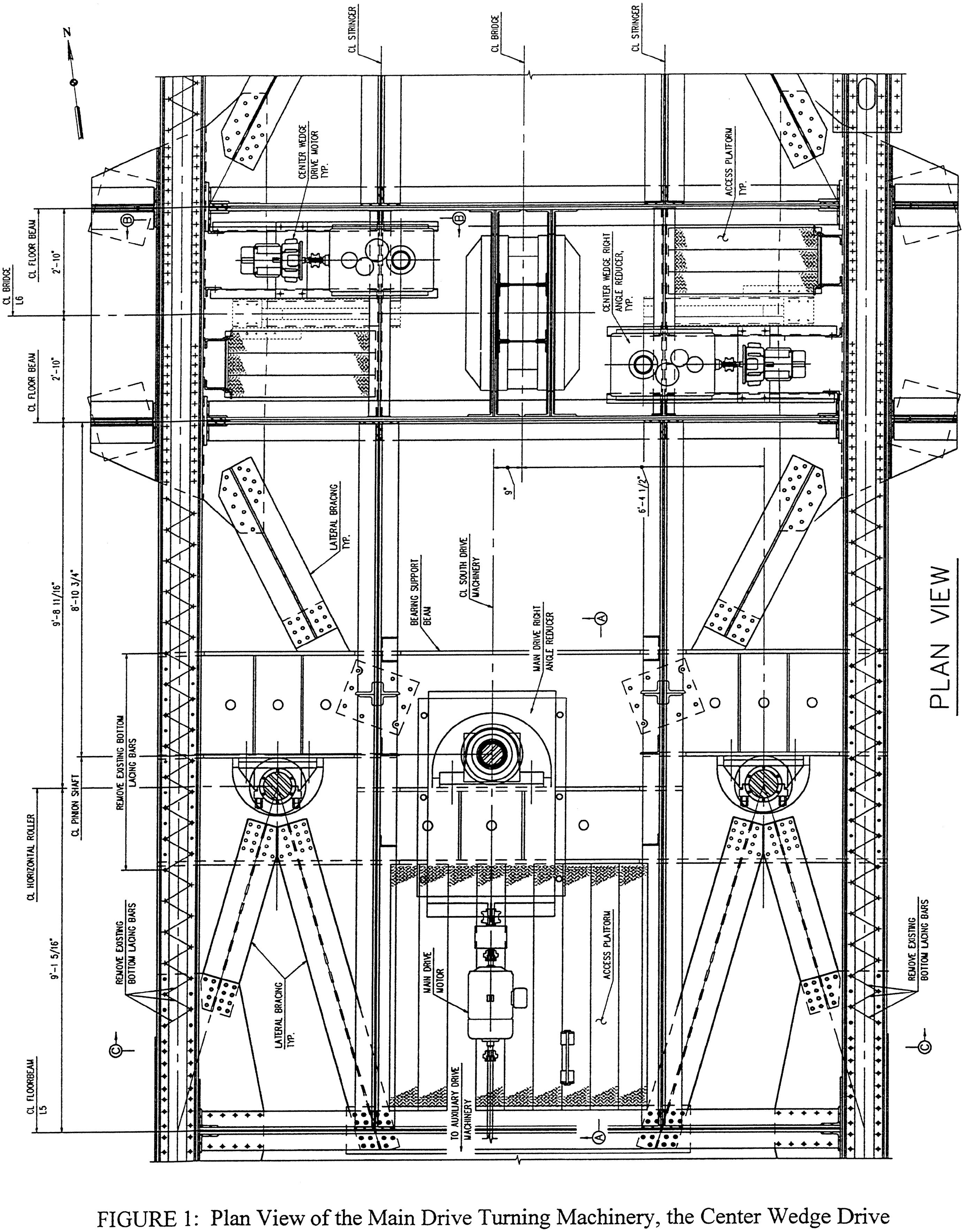

FIGURE 1: Plan View of the Main Drive Turning Machinery, the Center Wedge Drive Machinery and the Bearing Support Beam

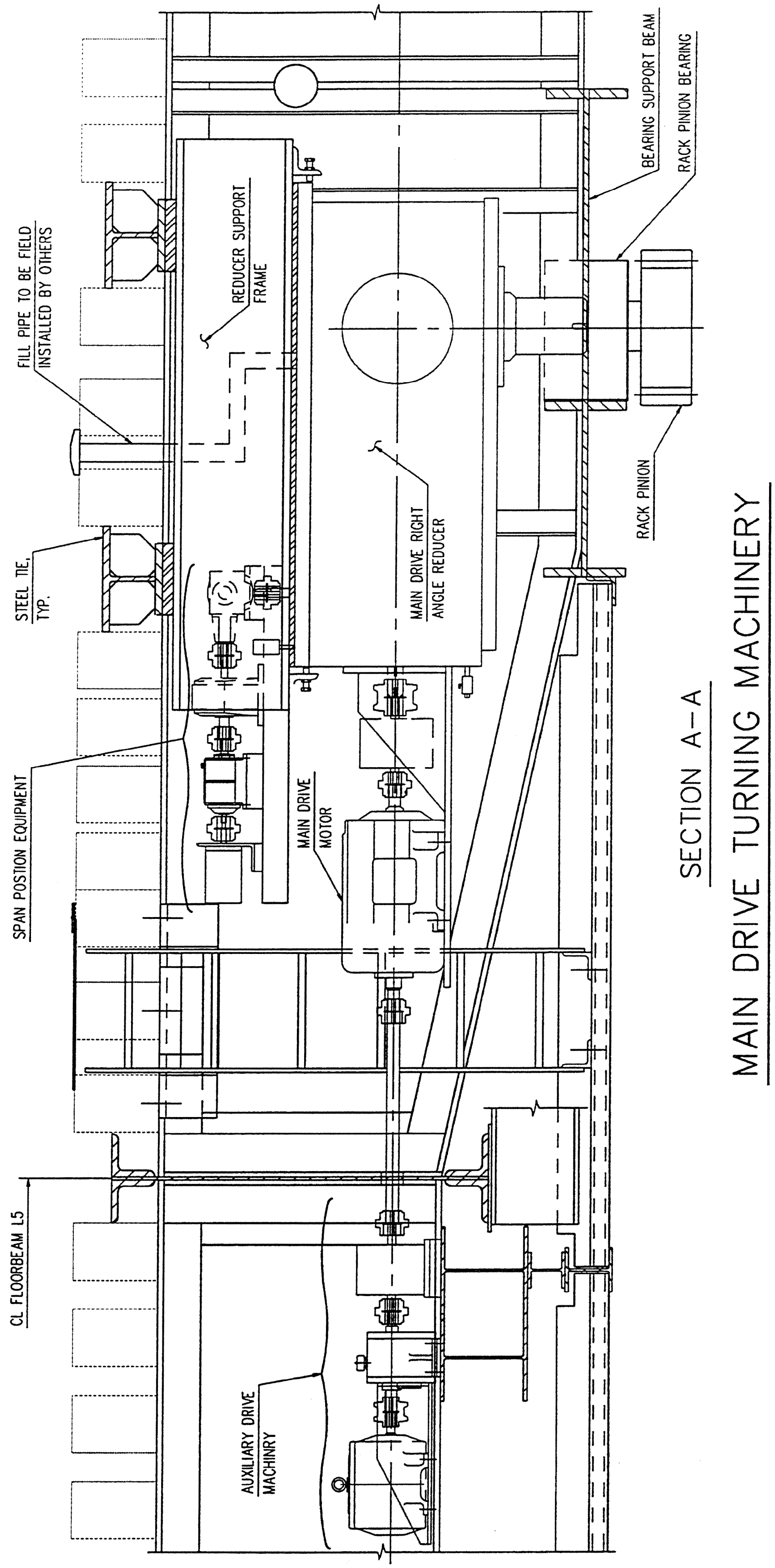

FIGURE 2: Cross Section View of the Main Drive Turning Machinery

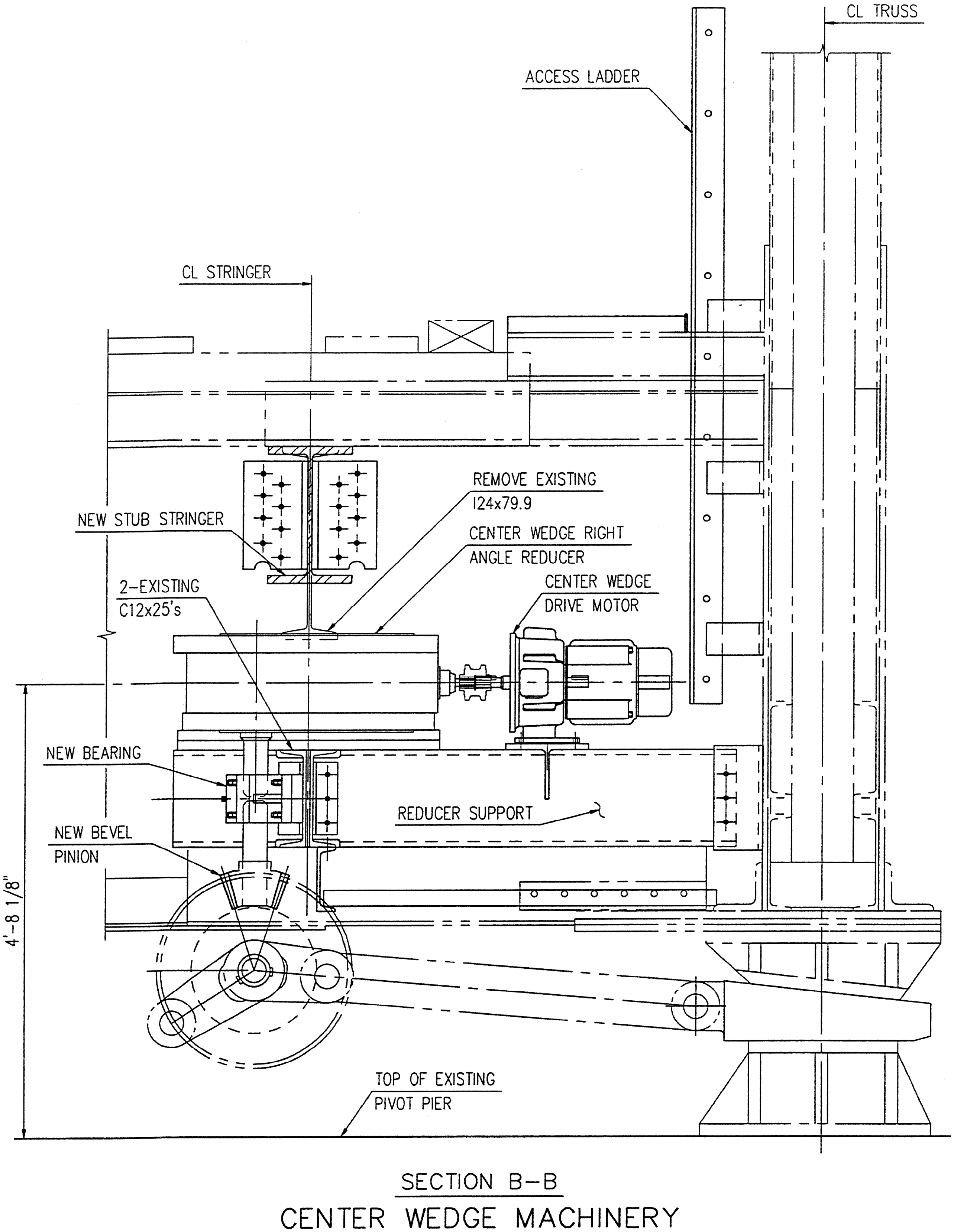

FIGURE 3: Cross Section View of the Center Wedge Drive Machinery

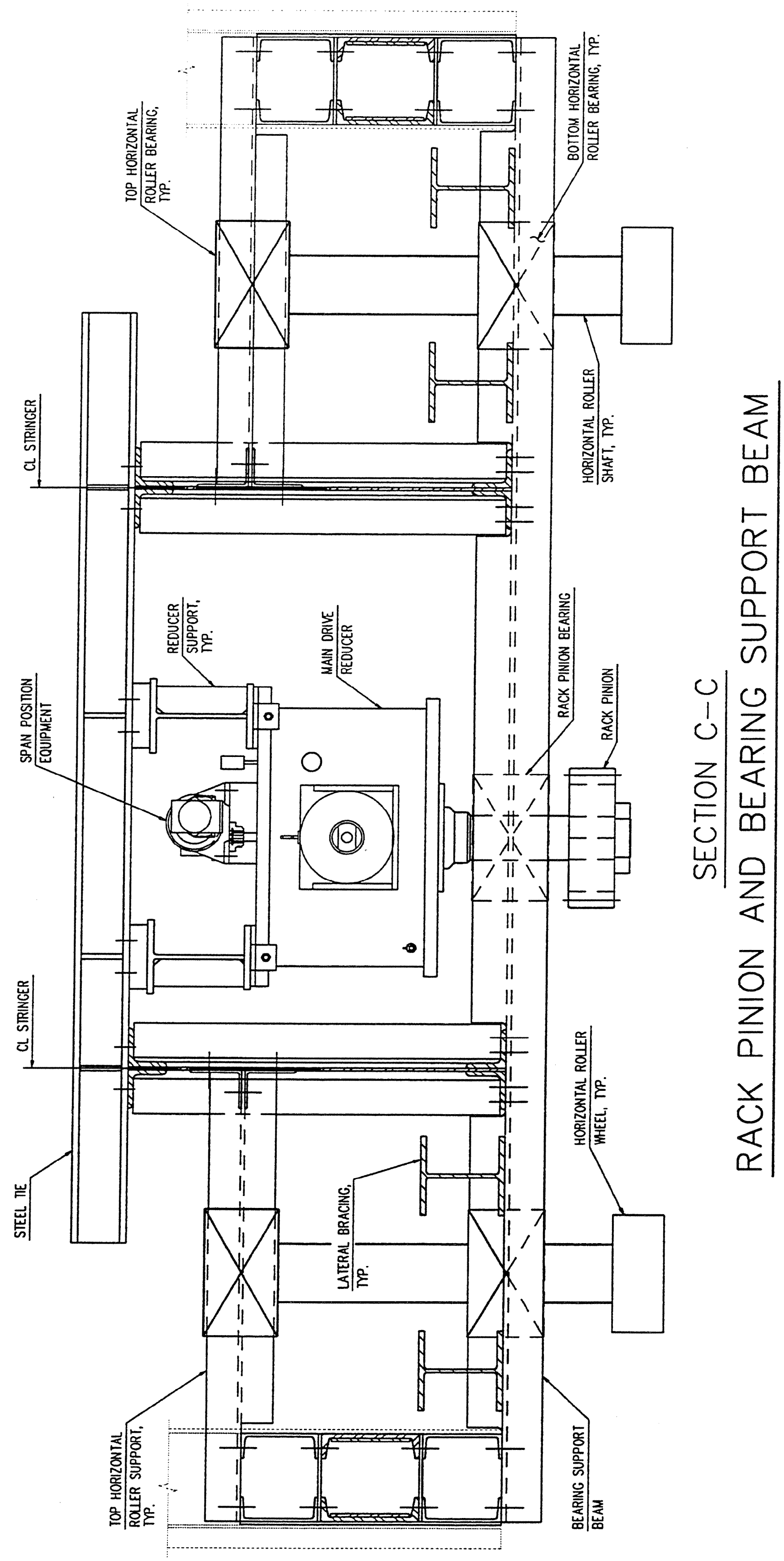

FIGURE 4: Cross Section View of the Bearing Support Beam and the Main Drive Reducer Support Frame

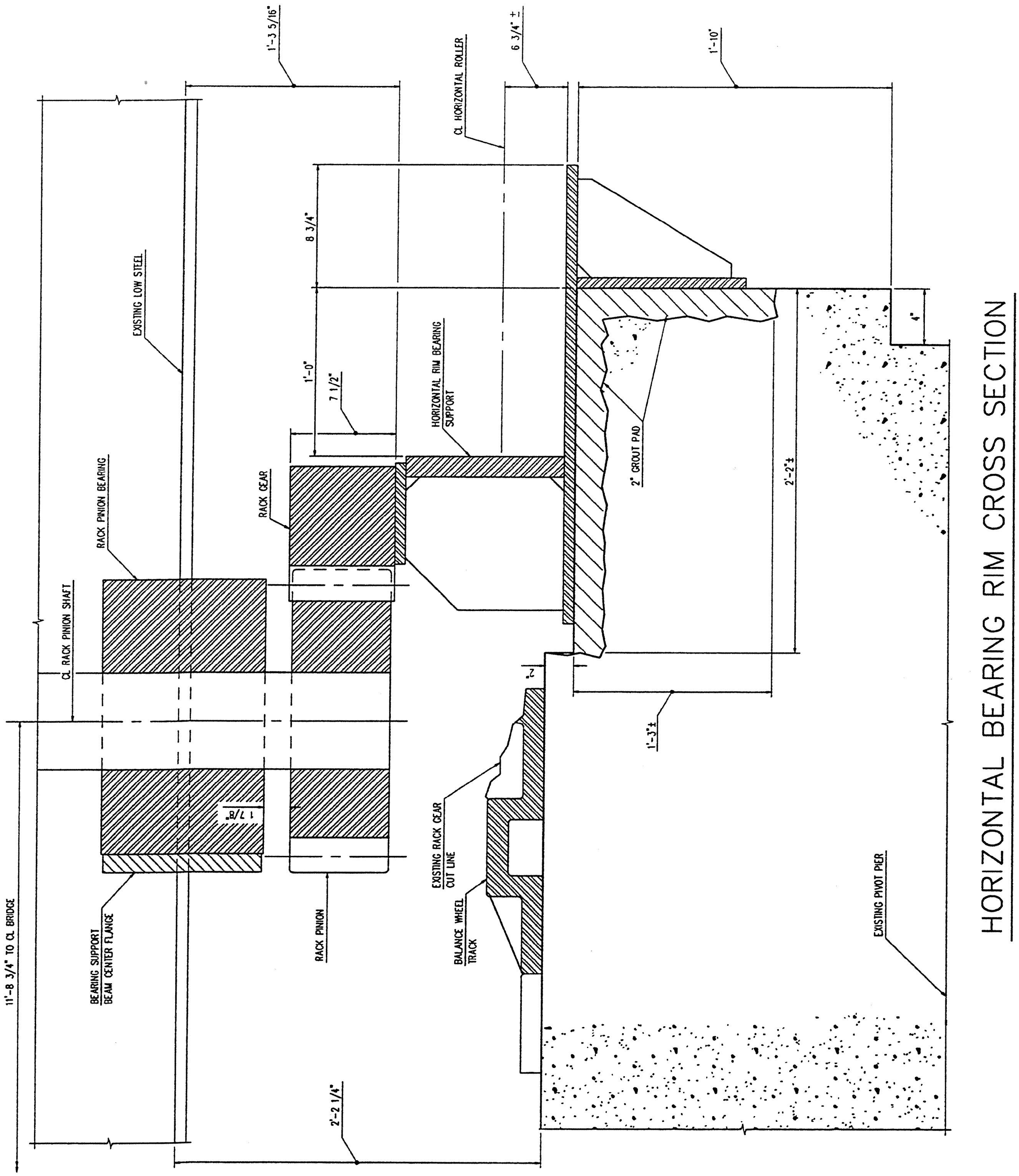

FIGURE 5: Cross Section View of the Horizontal Bearing Rim, Rack Gear and Rack Pinion