HEAVY MOVABLE STRUCTURES, INC.

EIGHTH BIENNIAL SYMPOSIUM

NOVEMBER 8 – 10, 2000

Grosvenor Resort
Walt Disney World Village
Lake Buena Visa, Florida

"Maintaining the Course of a Rehabilitation Under a Changing Scope of Services"

by Robert J. Tosolt, P.E.
Lichtenstein Consulting Engineers

MAINTAINING THE COURSE OF A REHABILITATION UNDER A CHANGING SCOPE OF SERVICES

UNIVERSITY AVENUE BRIDGE

PHILADELPHIA, PA

Prepared by:

Robert J. Tosolt, P.E.

LICHTENSTEIN CONSULTING ENGINEERS
One Oxford Valley Mall, Suite 818
Langhorne, PA 19047
(215) 752-2206

Prepared for:

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8th BIENNIAL SYMPOSIUM
LAKE BUENA VISTA, FLORIDA

NOVEMBER 2000

INTRODUCTION

The University Avenue Bridge is a double leaf trunnion bascule span that carries University Avenue over the Schuylkill River in Philadelphia, Pennsylvania. The bridge is 67'-4" center to center of outboard bascule girders providing four lanes for vehicular traffic and a pedestrian sidewalk on each side of the roadway. The movable leaves, which are symmetric, span 120 feet between trunnion centerlines and provide a clear channel of 100 feet with the span in the fully open position. The bridge is basically oriented north-south with the operator's house in the northeast quadrant.

The bridge, which is owned by Pennsylvania Department of Transportation (PADOT) but operated and maintained by the City of Philadelphia, was constructed in 1929 and partially reconstructed in 1983. A rehabilitation was performed in 1998-1999 according to plans developed by Lichtenstein Consulting Engineers (Lichtenstein) based on recommendations from a 1990 inspection of this bridge.

Between the time of the 1990 inspection when the scope for the rehabilitation was set, and the letting of the Contract in 1997, there was significant degradation of the mechanical systems. With the imminent onset of construction in 1998, Philadelphia's Bridge Maintenance Superintendent requested that several problematic machinery components not included in the current project be considered for rehabilitation or replacement.

This paper seeks to discuss how the project was kept on schedule despite an ever widening scope of services. Efforts to identify, inspect and address the troublesome systems within a moving time frame will be discussed, as well as the scheduling of the additional work to minimize its impact on the pre-existing construction schedule.

DESCRIPTION OF MACHINERY SYSTEMS

The structural and mechanical layout of University Avenue Bridge is uncommon by current design preferences. The bascule leaves are unusually broad and the superstructure is more akin to a twin double leaf bridge than a simple double leaf bridge. Each leaf is supported through four bascule girders, with each girder straddle mounted in a pair of trunnion bearings. One rack is mounted to the underside of each bascule girder while the mating rack pinion, and the remainder of the machinery, is mounted off the bascule pier. Each leaf is driven open or closed through four rack and rack pinion assemblies.

The rack and rack pinions are in actuality a pin and sprocket mesh: the pins (rack teeth) are mounted in angles attached to the underside of the bascule girders, while the sprockets (pinions) are all mounted on a common drive shaft . The common drive shaft spans the width of the bridge and is supported in four pair of sleeve bearings, one pair straddling each pinion. The common drive shaft is driven from each end by identical eletro-mechanical drives. Each drive consists of an electric motor driving a series of open gearsets which rigidly couple to the drive shaft. Each electro-mechanical drive is provided with two brakes, one motor brake and one emergency (machinery) brake. See Figure 1 at the end of this paper. In general the drive machinery is exceptionally stout, even by movable bridge standards. However, there is no mechanical load sharing between the two drives, and there is no provision to equalize loading among the four main pinions.

The movable leaves are equipped with a series of devices to stabilize and support the span in the closed position. Center locks are provided to position the span during closing and secure the bridge against undesirable movement when closed. Rear locks are provided to support the span when fully closed. Live load supports and live load reactions are provided to prevent overtravel of the span during closing and support the span in the fully closed position. See Figure 2 at the end of this paper.

The center lock machinery utilizes a lock bar configuration. A total of four lock bars are present, one adjacent to each bascule girder at the toe of the leaf. All lock bars are operated through common drive machinery. The center lock drive machinery consists of an electric motor that drives a common cross shaft through three sets of open reduction gears, bearings, shafts and couplings. Cranks and linkages driven off the cross shaft affect operation of the lock bars through rotation of the cross shaft. When retracted, each lock bar is supported in a front guide and a rear guide. When fully driven, each lock bar is supported in a front guide, a rear guide and a receiver. All components except the receivers are mounted under the roadway at the toe end of the south bascule leaf. The receivers are mounted opposite the front guides at the toe end of the north bascule leaf. See Figure 3 at the end of this paper.

The rear lock machinery utilizes a rocker-wedge configuration. Two wedges are present at the rear of each leaf, one centered between each pair of bascule girders. As with the center lock machinery, the rear locks are operated through common drive machinery. The rear lock drive machinery consists of an electric motor that drives a common cross shaft through three open gearsets, bearings and couplings. A fourth open gearset located at either end of the common cross shaft drives a linkage which affects operation of the rocker into and out of contact with the wedge through rotation of the cross shaft. All components except the wedges are mounted on the rest piers. The wedges are mounted to the rear of the counterweight between each pair of racks. See Figure 4 at the end of this paper.

Neither the center locks nor the rear locks are equipped with emergency hand drives.

There are four live load supports and two live load reactions on each leaf. One live load support is located at the underside of each bascule girder between the trunnion and the waterway. The live load supports are intended to transmit the imbalance load and a portion of the loads due to vehicular traffic from the movable leaves to the bascule piers. Both live load reactions are located at the rear of the counterweight centered between each pair of bascule girders. The live load reactions are intended to provide additional stability and safety in the event of a problem with one of the live load supports.

ORIGINAL SCOPE OF WORK

The mechanical work called for in the 1996 Rehabilitation Plans encompassed a limited refurbishment of the span drive machinery and center lock machinery. No work was specified for the rear lock machinery or the live load supports and reactions. The work included in the Rehabilitation Plans is summarized as follows:

Span Drive Machinery

1. Rehabilitate rack pinion bearing pedestals to include provision of new bushings, new anchor bolts, new cap bolts (turned bolts), and incidental items (ex. lube fittings, shims, liners, etc.)
2. Polish rack pinion shaft journals to an 8 microinch surface finish to provide maximum service life of new bushings.
3. Provide a limited number of new rack pins to replace existing pins identified in the rehabilitation documents.
4. Provide new keeper plates and hardware for the rack pins as identified in rehabilitation documents.
5. Bore rack support plates that have lost required fit with rack pin allowing radial movement of pin within support plates, as identified in rehabilitation documents.

Center Lock Machinery

1. Replace existing motor and open gearing with new enclosed reducer and new motor providing for emergency manual operation.

The preceding mechanical work was only a small facet of the total work to be performed as part of the rehabilitation. Major structural items included rehabilitation of the superstructure, replacement of the deck on the approaches, and a complete refurbishment of the electrical system. The limited mechanical work was to be coordinated with and performed under the confines of the traffic staging and maintenance which was required as part of the structural work.

AWARD OF CONTRACT

The Contract was let through PADOT in Summer 1997. Buckley Construction Co., Philadelphia, PA was selected as the general contractor for the project.

Buckley employed mechanical subcontractor Cornell & Company, Westville, NJ.

PADOT provided resident engineering project administration and review for the project. URBAN Engineers provided CEI services for the project.

Lichtenstein provided construction engineering services, including shop drawing review, constructability review, shop inspection and field inspection.

WIDENING SCOPE

Pre-construction meetings were held in fall 1997 at which the Contractor divulged and received approval for the project schedule. The Contractor, thereafter, obtained the necessary permits and mobilized to begin construction activities in Spring 1998. However, two events transpired to widen the scope of mechanical work and alter the project schedule.

The first event involved the actual scope of mechanical rehabilitation work. Philadelphia's Bridge Maintenance Superintendent submitted a memo to the Contractor in February 1998 asking that the Contractor widen the scope of work to include several mechanical systems not included within the scope of the current rehabilitation. The City's memo identified the following mechanical systems as being deficient:

1. Emergency Brakes in the machinery rooms were disconnected since they would not release fully.
2. Motor Brakes on the four main drive motors did not work properly.
3. Rear Lock Machinery malfunctioned occasionally.
4. Center Locks had too much play between lock bar and shoe.

While the scope of the rehabilitation had initially been approved by PADOT in 1991, the actual plans were not finalized until 1996 due to funding considerations. However, during this time, and through the onset of construction in 1998, there had been no indication that the current scope of the project did not adequately address all known concerns, or that additional problems had developed in the interim. The above concerns were not brought to the attention of PADOT until the Contractor forwarded the City's memo.

The above emphasizes the importance that owner, operator and maintainer, whether separate entities or separate divisions of the same entity, communicate and facilitate open exchange of information. PADOT owns the bridge. The City is responsible for the day to day operation and upkeep of the bridge. The two administrations function independently. While it is not clear at what point the City was aware of the above deficiencies, had these deficiencies been brought to PADOT's attention prior to the letting of the Contract, they could have been included within the original scope of the rehabilitation, as opposed to being added as supplemental items to be performed on a Time and Material basis.

The second event involved how field conditions at the time of the rehabilitation impacted the work specified in the rehabilitation plans. In late summer 1998 the Contractor initiated the rack pinion shaft work. The rack pinion shaft work was the most involved of the mechanical activities specified on the rehabilitation plans. To perform this work, the bearing pedestals had to be removed from the site and shipped to a shop to be reworked, during which time the bridge would be out of service to marine traffic. It was intended that this work would be performed in conjunction with a bridge closure during which time the superstructure would be cleaned and painted.

Preparatory work was required to facilitate smooth operation during the shutdown period. To this end, the Contractor replaced the bearing cap bolts, which were severely corroded, with new temporary studs and performed a 'dry run' of the bearing cap removal prior to the closure period to ensure smooth progress. During this preparation work, it was discovered that the shaft journals were in an advanced stage of deterioration. Given the state of corrosion of the shaft journals, the Contractor stated that it would not be possible to polish shaft journals to the requisite finish.

The rack pinion bearing caps had not been removed during the 1990 inspection due to the limited scope of the project. Therefore, reasonable assumptions had to be made in the formulation of the rehabilitation plans for these components. The plans had been based on prior rehabilitation of similar components on other bridges assuming similar conditions. The existing conditions negated this assumption. The discrepancy between the expected condition and the existing condition was significant.

DISCUSSION OF DEFICIENT CONDITIONS

Lichtenstein conducted a limited inspection to evaluate the deficient conditions identified by the City and Contractor, and to assess what corrective action(s) was warranted. Due to the advancing schedule of the project, the inspection had to be conducted in the midst of construction work. Those safety features typically used but seldom needed during inspection work, including safety glasses, hearing protection and hard hats, were now a necessity due to demolition work, and respirators were required due to dust levels and fumes from the iron worker's torches. The inspection of the rear lock machinery became particularly hazardous when the demolition crew began breaking up the deck immediately above the inspectors heads.

The machinery appeared to be adequately maintained at the time of the 1990 inspection. In contrast, the findings of the current inspection substantiated that all of the City's claims warranted rehabilitation or replacement.

The following summarizes the inspection of the deficient conditions identified by the City and Contractor. Significant findings, and proposed corrective actions, are discussed.

<u>Machinery Brakes</u>

The existing machinery brakes were spring set, solenoid released brakes. The overall external condition of the emergency brakes was adequate, however the brakes were non functional. Conversation with City maintenance personnel revealed that the brakes had been electrically disconnected after they began to smoke and malfunction during operation. The apparent cause of the malfunction was a deterioration of the solenoids.

Given the substantial size of the brakes (28" diameter brakewheel), replacement would be a costly choice. Since the linkages for theses brakes were generally in good condition, Lichtenstein recommended rehabilitation of the existing machinery brakes and provision of new coils for the solenoid.

Motor Brakes:

The existing motor brakes were spring set, solenoid released mill type brakes mounted on one end of the double extended motor shafts. A feature of a mill type brake is that the brakewheel is mounted on a tapered shaft and secured by a lock nut. This lock nut was missing at two of the four motor brakes. This condition could result in the brakewheel working its way off the end of the motor shaft thereby disabling the brake. There was evidence of axial movement at both locations where the nut was missing. An additional deficiency was that the spring lengths for the motor brakes were observed to be set well below the minimum length recommended on the brake data plate.

Since the motor brakes are smaller (12" brakewheel) and much more inexpensive than the machinery brakes, and since solenoid type brakes are not the preferred brake type for the given application, Lichtenstein recommended replacement of the motor brakes with new spring set, thrustor released brakes.

Brake Deficiency Flag Letter:

With the machinery brakes disabled, the motor brakes providing minimal torque, and the possibility that an unrestrained brake wheel could be lost thereby further decreasing the braking capacity of the system, operation of the bridge was hazardous. Lichtenstein submitted a flag letter detailing these findings immediately following the inspection and recommended that the bridge be taken out of service until the capacity of the motor brakes was restored and the unrestrained brake wheels secured. The City subsequently adjusted the spring lengths as per Lichtenstein's recommendation to provide braking torque comparable to full load torque of the motor, and also acquired and installed new nuts to secure the motor brakewheels. During the next scheduled bridge opening following these corrective actions, operational problems with the bridge were experienced. Subsequent inspection and testing of the motor brakes revealed that the solenoids for the motor brakes provided only nominal force and could not release the brake if adjusted above the minimum setting. As a result the motor brakes had to be adjusted to their minimum setting.

While this was not a desirable situation and it was not condoned by Lichtenstein, it should be noted that behavior of the bridge during operation did not necessitate the use of brakes. Indeed this point was proven beyond doubt, when through the course of construction, it was noted that the replacement nuts used to secure the motor brakewheels had fallen off, as had the brakewheels, yet the bridge continued to operate. Whether due to electrical control or system friction, the bridge did not exhibit any drift when stopping.

Rear Lock Machinery

The rear lock machinery exhibited multiple deficiencies.

The brakes for the motors had been partially disassembled leaving the machinery without braking. The machinery did not exhibit any signs of recent lubrication. As a result, the bushing of two bearings had frozen due to lack of lubrication and rotated out of their housings, and a bushing for a third bearing had fractured. The machinery was improperly adjusted and controlled. The inadequate control was evident throughout the inspection as the locks did not engage consistently, and was highlighted in one particular instance when the operator overdrove the locks resulting in the final pinion and segment gear at one corner of the bridge coming out of mesh. These components had to be manually re-engaged.

Given the above deficiencies, significant rehabilitation of the rear lock machinery was required to ensure reliable service of the machinery in the long term. Lichtenstein recommended that the machinery at the corners of the drive be removed to a shop for rehabilitation. Lichtenstein recommended new bushings and pins, and refurbishment of the castings.

Center Lock Machinery

The measured clearances between all lockbars and guides exceeded an RC6 fit, which is the AASHTO specified fit for the given application. Three of the four receivers were missing at least one guide shoe, allowing relative movement in excess of ½" at the tips of the leaves. Lichtenstein recommended that the guides, receivers and lockbars be removed to a shop for rehabilitation. Lichtenstein recommended that the guide and receiver castings be refurbished, and that new bronze wear shoes be provided.

Live Load Supports and Reactions

Though not specifically identified by the City as being problematic, these assemblies lend stability to the lift span when seated and could contribute to undesirable movement of the leaves under live load of traffic if improperly adjusted. Inspection of the live load supports revealed that these components were moderately to severely corroded and were not providing support to the leaves when seated. Inspection of the live load reactions revealed that these components were in a state of disrepair such that they were completely ineffective. Lichtenstein recommended that the existing supports and reactions be replaced in-kind with new components.

Rack Pinion Shaft Journals

Simply stated, the rack pinion shaft journals exhibited the worst corrosion of any mechanical component previously observed by the inspectors (engineers/staff). The entire width of multiple journals exhibited corrosion so severe that there was no evidence the surface had originally been machined. These journals had a battered appearance similar to kneaded dough, and preliminary estimates were that valley to peak variations were in excess of 1/8". The amount of material removal required to clean up the journals could not be achieved through a polishing operation. Cutting and grinding operations would be necessary. These operations could not be efficiently performed in the field considering the number of journals requiring cleanup and the limited timeframe that would be allotted for the work. The shafts needed to be removed from the bridge and shipped to a shop to be reworked.

SCHEDULING

A primary concern in evaluating how the additional work would impact the existing project schedule was determining what special bridge closures, either to marine or vehicular traffic, would be involved. University Avenue Bridge is a heavily traveled vehicular and pedestrian throughway between Center City and South Philadelphia. Therefore, emphasis was placed on utilizing roadway and lane closures already arranged in the project schedule to minimize the inconvenience to the public. While the bridge has only a handful of openings for marine traffic each week, it opens almost exclusively for barges carrying fuel to a PECO plant located upriver of the bridge. This arrangement was an asset to work requiring short term closures, since the work could be scheduled around the bridge openings. However, it posed a substantial obstacle to work requiring a lengthy closure, since the fuel would need to be re-routed to the PECO plant via truck at considerable cost.

Lichtenstein determined that all of the deficient items identified by the City, while increasing the involvement of the mechanical subcontractor in the project, did not impact the existing construction schedule. The additional work at the machinery brakes could be performed independent of all other rehabilitation work and traffic considerations. The additional work at the motor brakes, while largely independent of other work, did require a limited closure to marine traffic, however this work could easily be sequenced between scheduled bridge openings. The additional work at the center locks and rear lock machinery entailed traffic lane closures to prevent live load on top of the leaf with the locks removed. However, the majority of this additional work for the locks could be sequenced to coincide with lane closures for the structural work; rehabilitation of the span locks and rear lock machinery for one half of the bridge would be scheduled to coincide with the traffic lane closures for that half of the bridge.

The installation and alignment of the center lock guides and receivers required a complete traffic closure as the leaves had to be partially opened to perform this work. Likewise, the proposed live load support rehabilitation required that the leaves be opened in order for the existing supports to be removed and the new supports to be installed. This work could not be sequenced with the previously scheduled closures. However, to minimize disruption to traffic, this work could be performed in a sequence of overnight closures.

Having established that the above work could be sequenced within the confines of the existing schedule, Lichtenstein was faced with the challenge of providing plans on a timely basis in the face of an advancing construction schedule. Lichtenstein had performed the limited inspection in mid-February'98 and early March'98 and submitted the inspection report at the beginning of April'98. Having received approval from PADOT for the additional work shortly thereafter, Lichtenstein provided two supplemental drawing packages and specifications, one each for the center locks and live load rehabilitation and for the rear lock machinery rehabilitation, by August 2, 1998. Lichtenstein provided separate supplemental specification packages to address the motor brake replacement and machinery brake rehabilitation. As these items did not affect the critical path of the construction schedule, they were not addressed until July 1999.

The sole item which severely and unavoidably impacted the project schedule was the discovery of the corrosion on the rack pinion shaft journals. The condition of the journals necessitated that they be rehabilitated in a shop. However, the size of the shafts posed substantial obstacles to their rehabilitation planning.

The rack pinion shafts are exceptionally large even by the standards of movable bridge machinery. Each rack pinion shaft is 40 feet long and weighs 34,000 pounds, and the main drive shaft for each leaf comprises two such shafts. The overall size of the shafts immediately limited the number of machine shops capable of performing the necessary work, increased the machining time to clean up the journals, and increased the difficulty of handling the shafts during removal and installation at site. All of these factors combined to lengthen the duration of the bridge closure which would be necessary to perform this work. The bridge closure that had been scheduled for the rehabilitation of the rack pinion shaft bearing pedestals was not sufficient for the work required to rehabilitate the rack pinion shaft.

Lichtenstein contacted multiple machine shops to identify shops capable of performing this work, to establish a timeframe for the machine work, and to obtain competitive quotes for the work. Lichtenstein then worked in conjunction with PADOT , PECO and the Coast Guard to schedule the necessary bridge closures to marine traffic for this additional work. Two four week outages separated by one week of operation were agreed upon for April through June 1999.

COORDINATION AND FACILITATION OF REHABILITATION WORK

The first major bridge closure scheduled as part of the original project was performed in Fall 1998. For five weeks starting on September 7, the bridge was closed to marine traffic. Due to a miscommunication between the general contractor and the mechanical subcontractor, no mechanical work was performed as part of this outage. As a result of this missed opportunity, PADOT increased Lichtenstein's involvement to facilitate and coordinate the field work and shop work. Overruns or incompletion of the work due to lack of planning or communication during the closures scheduled for the rack pinion shaft rehabilitation could not be tolerated since the cost would be prohibitive. For each day that a fuel barge was delayed from delivering its cargo to the PECO power plant following the scheduled closure, PADOT would incur a $10,000 per day charge which represented the cost differential between barging and trucking fuel to the PECO plant. To maintain an accurate assessment of progress of the project, Lichtenstein communicated with both the Contractor and the Machine Shops. Lichtenstein provided coordination between the two as necessary.

Lichtenstein established direct interaction with the machine shops involved in the rehabilitation and provided shop drawing review, at times at the manufacturer's facility. Lichtenstein provided shop inspection of rehabilitated parts and addressed questions on-site. Lichtenstein coordinated significant dimensions between shops working on mating components; in particular the coordination of the journal diameters and the rack pinion bushing I.D's was crucial. Lichtenstein maintained a timeline of part completion versus elapsed closure time to chart the progress of the rehabilitation.

Lichtenstein witnessed significant field work and oversaw installation of rehabilitated components, and provided field support and worked in conjunction with the Contractor to ensure proper installation and alignment of rehabilitated components.

CURRENT STATUS

Despite the expanded scope of work, the project was kept on schedule as a result of cooperation between the owner, operator, contractor and engineer. Close coordination between engineering, manufacturing, and construction was required to ensure that the additional work could be implemented in the face of an advancing schedule.

At the present time the rehabilitation of the mechanical systems has been successfully completed with minor exceptions. However successful the rehabilitation though, the machinery can not be rehabilitated and then abandoned; the machinery cannot withstand repeated abuses without a foreshortened life. The fact that the machinery at University Avenue Bridge is still functional after falling into disrepair is testament to its conservative design. On many other bridges, deterioration of the magnitude observed at University Avenue would have certainly resulted in the need for complete replacement.

With only two movable bridges in the entire state, knowledge of and funding for upkeep and maintenance of these bridges is low. Lichtenstein is currently working in conjunction with PADOT and the City to develop a maintenance manual, schedule and procedures. As with all movable bridges, the owner must provide funding and maintainers must implement and maintain an effective maintenance program to ensure the reliable long term service that machinery can provide.

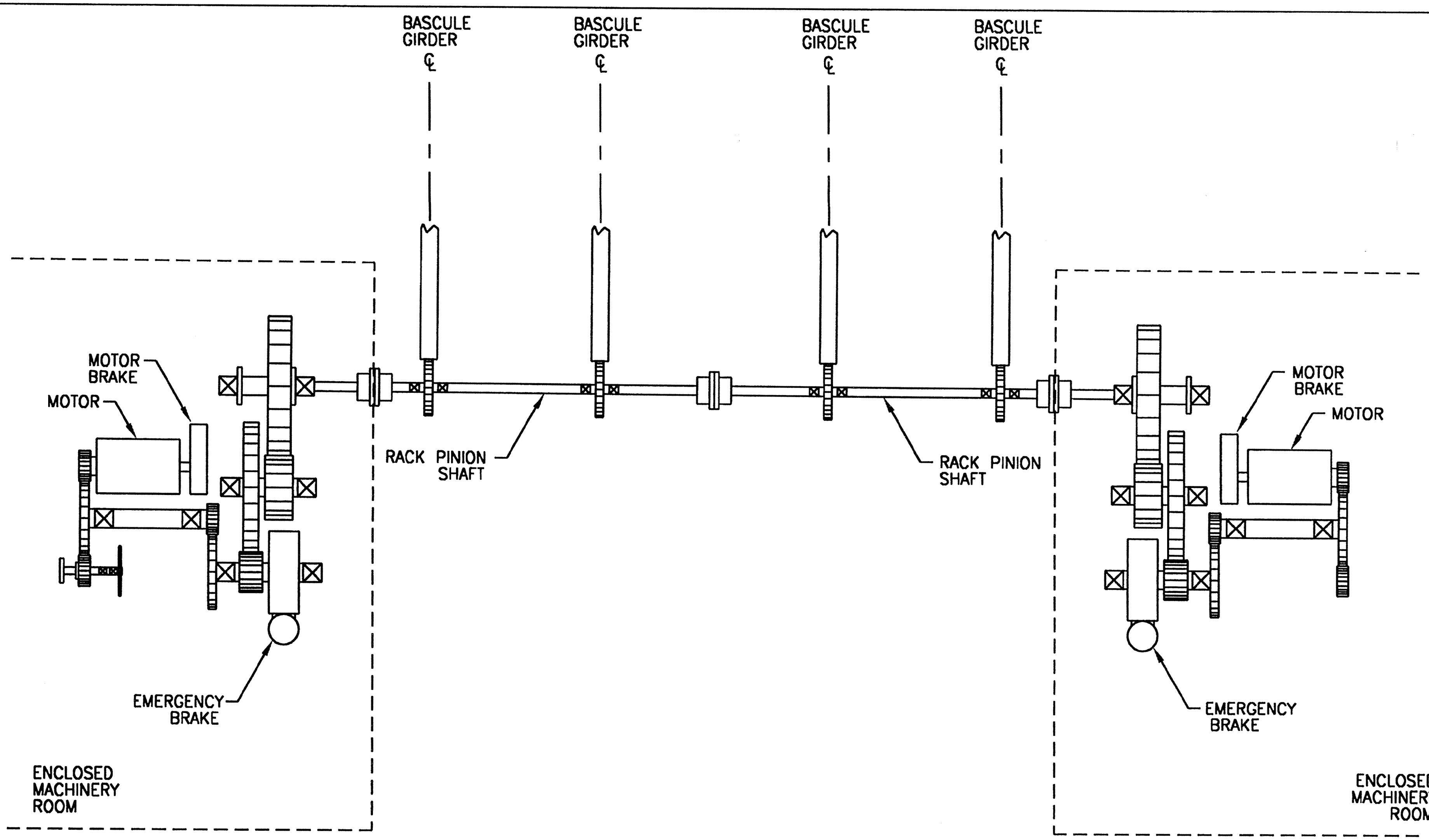


Figure 1. Span Drive Machinery

Project:	Prepared for:
University Avenue Bridge Philadelphia, PA	Heavy Movable Structures 8th Biennial Symposium Lake Buena Vista, Florida
	Prepared by:

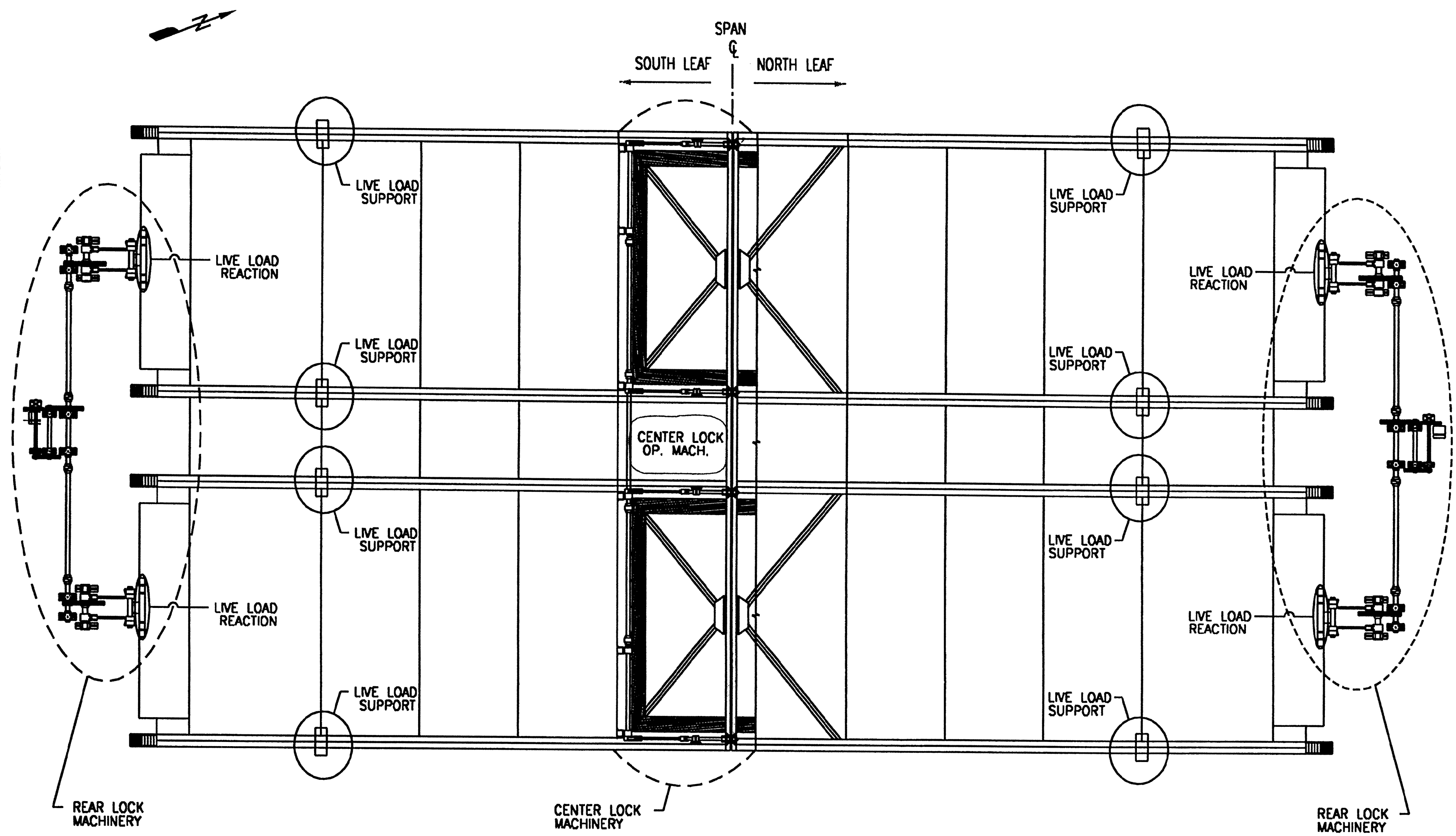
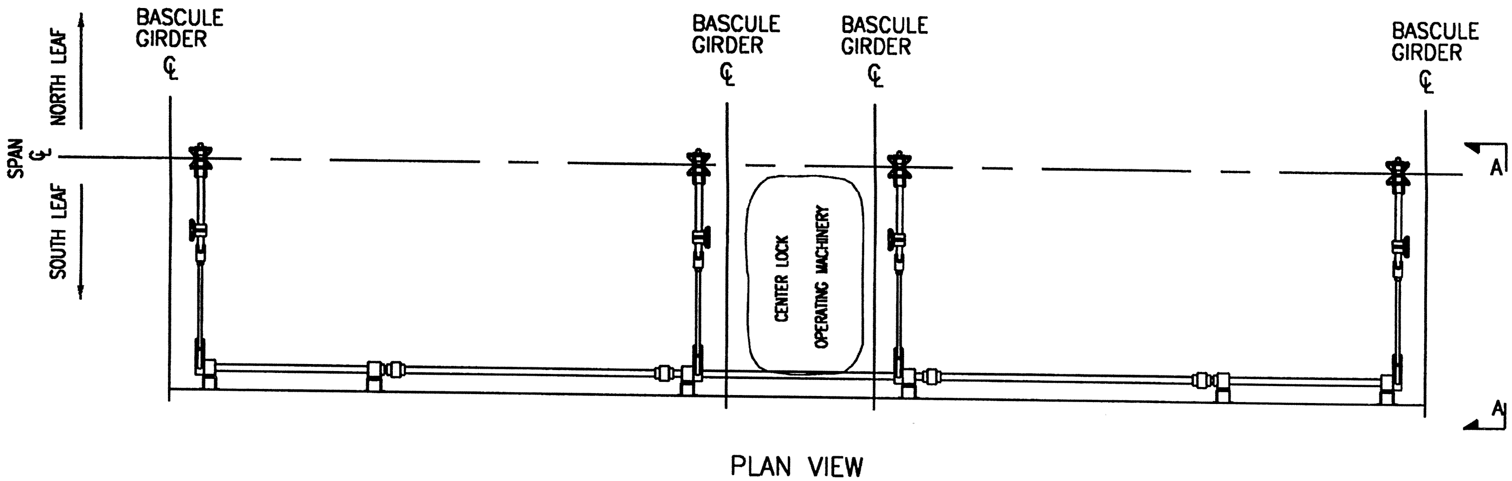


Figure 2. Plan View of Movable Leaves and Span Support Machinery

Project:
University Avenue Bridge
Philadelphia, PA

Prepared for:
Heavy Movable Structures
8th Biennial Symposium
Lake Buena Vista, Florida

Prepared by:
Lichtenstein Consulting Engineers



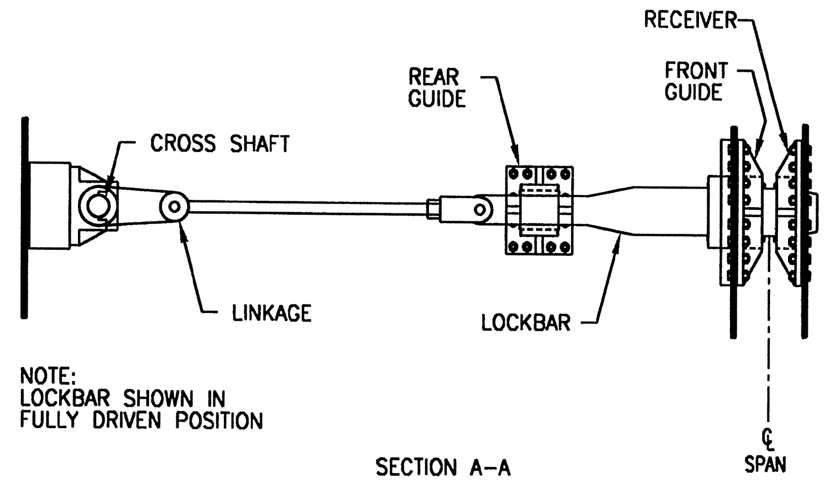


Figure 3. Span Drive Machinery	Project: University Avenue Bridge Philadelphia, PA	Prepared for: Heavy Movable Structures 8th Biennial Symposium Lake Buena Vista, Florida Prepared by: Lichtenstein Consulting Engineers

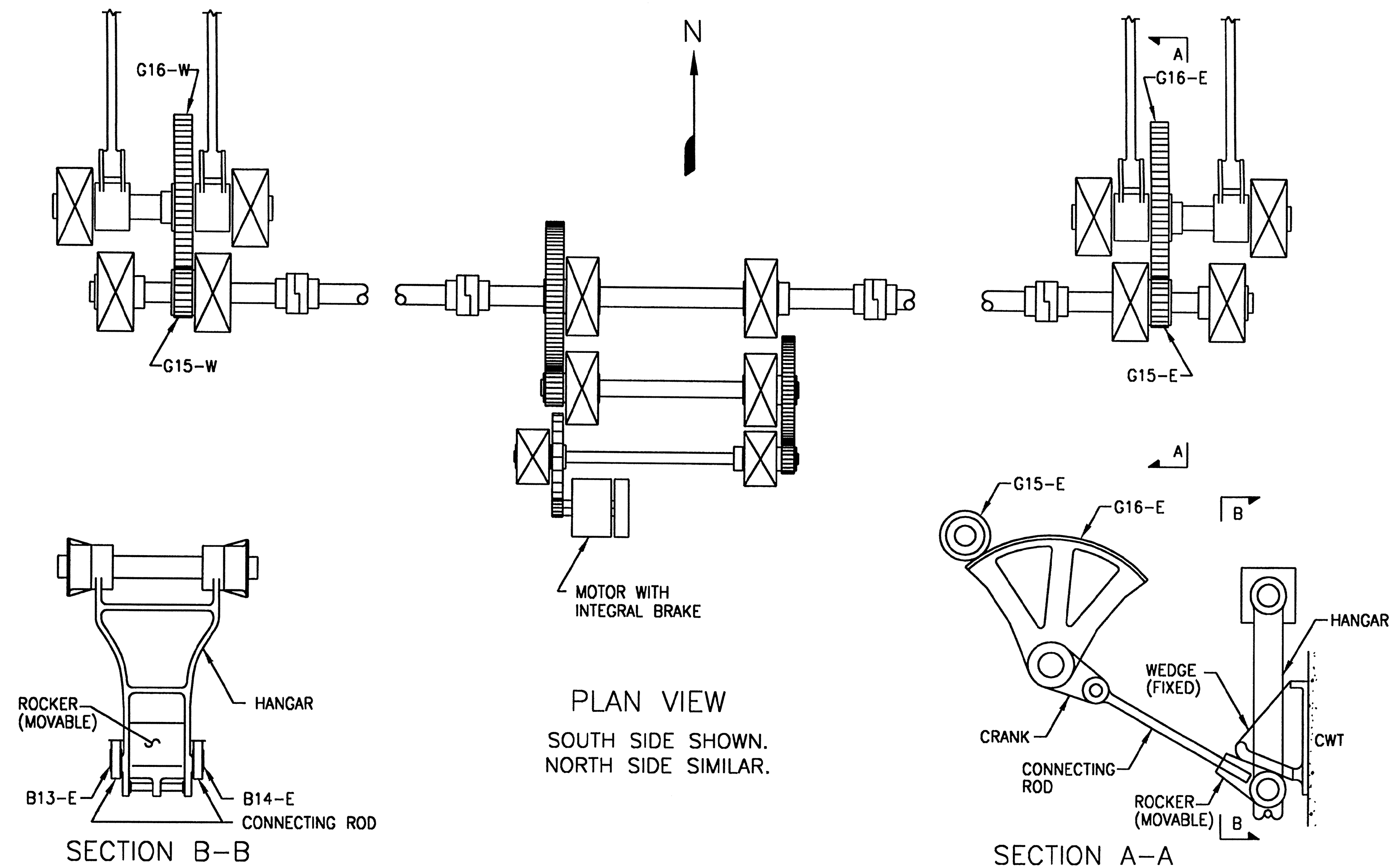


Figure 4. Rear Lock Machinery

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University Avenue Bridge Philadelphia, PA	Heavy Movable Structures 8th Biennial Symposium Lake Buena Vista, Florida
	Prepared by: Lichtenstein Consulting Engineers