MACHINERY REHABILITATION FEASIBILITY STUDY

JOHNSON STREET HIGHWAY AND RAILROAD BRIDGE
VICTORIA, BRITISH COLUMBIA

Submitted to: Mr. Jim Fowler
MMM Group Limited

Prepared by: Paul Bandlow

Stafford Bandlow Engineering, Inc.

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PAUL M. BANDLOW
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Introduction

The purpose of this evaluation was to investigate the feasibility of rehabilitating the mechanical and electrical systems on the Johnson Street Highway and Railroad Bridges and to develop budgetary cost estimates for the rehabilitation.

The mechanical and electrical systems are discussed separately in the following text. The condition of the electrical systems is such that complete replacement is the only viable option and therefore discussion of the electrical systems is limited.

Mechanical Systems

General

The Johnson Street Bridge consists of two side by side single leaf Strauss heel trunnion bascule bridges, circa 1922. Both bridges are 148’-8” long from the heel (main) trunnion to the live load supports. One bridge carries three lanes of vehicular traffic and is 33’-6” wide. The other bridge carries a single railroad track and is 22’-6” wide. The bridges are basically oriented in an east-west direction.

Although there were many bridges of this type built throughout North America they are among the most complex movable bridge types ever built. While there are advantages to the mechanical design these advantages do not come without complications especially when compared to current movable bridge designs.

The bridge structures consist of a parallelogram arrangement that allows the structure to change shape as the bridge opens. The arrangement uses eight large bearings (span support machinery), one at each corner of the parallelogram for each truss, to allow for the movement of the structure. See Figure 1, Appendix. All of these bearings are critical to the operation of the bridge. All of the bearings are under load at all times and therefore cannot be replaced without first unloading the bearings. The construction of the bearings is such that even when unloaded, replacement is difficult.

Any rehabilitation of the bridge therefore must consider the integral nature of the bearings with the moving structure. In order to ensure reliable operation of the bridge over the design life of the rehabilitation, the condition and life expectancy of these bearings is the most critical element with regard to the rehabilitation of the mechanical machinery.

The span drive and span lock machinery must also be considered as part of any rehabilitation. This machinery must be reliable and safe to operate for the anticipated life of the bridge following the rehabilitation. Unlike the major bearings that connect the structure, the span drive and span lock machinery are not integral with the structure and these components are more readily replaced.

The span support bearings, span drive machinery and span lock machinery were each evaluated as part of this study. Information used in the evaluation included available drawings for the bridge, an inspection report based on a 2008 inspection and limited analysis of the bridge machinery in accordance with the requirements of the Canadian Highway Bridge Design Code (CHBDC). No field investigation was conducted as part of this work. A discussion of our assessment of each of the machinery systems is provided below.

Span Support Machinery

The span support machinery consists of two counterweight trunnion bearings, two main trunnion bearings and four link pin bearings and is essentially the same configuration for both bridges. The only variation is that similar components on the railroad bridge are smaller since the loading is less than at the highway bridge.

All of the span support machinery bearings are located in confined or inaccessible areas. Each bearing is mounted between structural steel plates and, as a result, bearing clearances which are an indication of wear cannot be readily obtained. Due to the bearing construction, only the main and counterweight trunnion bearings can be opened (bearing cap removed) for inspection of the wearing surfaces. The caps were not removed as part of the 2008 inspection and therefore the condition of the wearing surfaces of the bearings is not known.

The span support machinery bearings are in fair condition externally and there was no evidence of major problems with these bearings at the time of the 2008 inspection. The long term performance of these bearings cannot be predicted without knowledge of the condition of the wearing surfaces. In addition, it is noteworthy that we are unaware of a similar movable bridge bearing installation with a proven service life that is significantly longer than the time of service that has already been seen at the Johnson Street Bridge.

It is expected that the load in the span support bearings will increase by approximately 10% as part of the strengthening required to withstand current seismic loading requirements. It is reasonable to expect that the increased loading will result in accelerated bearing deterioration.

The span support bearing pressures under the original (and presumed present) loading conditions range from 1,270 psi at the main trunnion bearings on the railroad bridge to 1,550 psi at the 2nd link pin bearings on the highway bridge. The bearing material is identified as phosphor bronze on the original drawings for the bridge. This description is not sufficient to identify the properties of or the allowable bearing pressure for the material. For trunnion bearings the CHBDC provides an allowable bearing pressure of 1,500 psi. Based on this allowable bearing pressure, four of eight bearings on both the highway bridge and the railroad bridge are slightly overstressed under current loading conditions.

With the increased loading six out of eight bearings on each bridge are overstressed with some bearings exceeding allowable limits by more than 10%. Reducing the stresses to allowable limits per the CHBDC will require replacement of the overstressed bearings with larger bearings. The bearings stresses for the present and rehabilitated condition for both bridges are provided in Tables 1 and 2 below.

HIGHWAY BRIDGE BEARINGS				
	Original Loading		Modified Loading	
Bearing Identification	Bearing Stress (psi)	% Allowable	Bearing Stress (psi)	% Allowable
Main Trunnion Bearing	1333	89	1466	98
CWT Trunnion Bearing	1382	92	1520	101
1st CWT Link Pin	1493	100	1642	109
2nd CWT Link Pin	1550	103	1705	114

Table 1. Highway Bridge Bearing Stresses. Highlighted values indicate an overload condition.

RAILROAD BRIDGE BEARINGS				
	Original Loading		Modified Loading	
Bearing Identification	Bearing Stress (psi)	% Allowable	Bearing Stress (psi)	% Allowable
Main Trunnion Bearing	1270	85	1397	93
CWT Trunnion Bearing	1515	101	1667	111
1st CWT Link Pin	1389	93	1528	102
2nd CWT Link Pin	1523	102	1675	112

Table 2. Railroad Bridge Bearing Stresses. Highlighted values indicate an overload condition.

Three options were considered with regard to the span support bearings as follows:

1. Do not inspect or replace the bearings and maintain the bearings for their remaining life.
2. Inspect the bearings to the extent possible and base the rehabilitation effort on the results of the inspection.
3. Replace the bearings with larger bearings that meet the requirements of the CHBDC.

Option 1 has the most risk and is not recommended as it is possible that the internal condition of the bearings is poor and the proposed additional load could result in rapid deterioration of the bearings. Our experience is that the external condition of the bearings is not a good indicator of the internal condition.

Option 2, the inspection of the bearings, allows for a limited view of the main and counterweight trunnion bearings. If the condition of the wearing surfaces is poor, the decision to rehabilitate the bearings is obvious. If the condition of the wearing surfaces is good, it would be safe to assume that the bearings would last for the long term under the current loading conditions. Note that Option 2 still leaves the condition of the link pin bearings as an unknown. The affect of the increased loading on the bearings is also unknown. Therefore this option also has inherent risk.

Replacement of the bearings allows for the necessary upgrades to meet the CHBDC requirements and it would be expected that with replacement the bearings would last for the life expectancy of the rehabilitation. The replacement option is the only option that reduces risk to the maximum extent possible.

If problems with the support components arise in the future, a significant additional rehabilitation will be necessary. This rehabilitation will likely involve significant cost, operational outages and associated delays. The cost to replace the span support bearings is included in the cost estimates near the end of this report.

Span Drive Machinery

The span drive for each bridge is normally driven by two electric motors. The motors provide power to a gear train that consists of open spur and bevel gears, sleeve type pillow block bearings and shafts. A differential is provided at the center of the drive train to allow for equal load sharing of the operating struts. The operating struts are located on opposite sides of the bridge. Each strut supports a rack (straight gear) that is driven by the final pinion in the drive train. The operating struts connect to the structure at the 2nd link pins. The drive machinery pulls the strut back through a guide assembly and causes the span to rotate about the main trunnion bearings.

Each of the span drives is provided with two motor brakes and two emergency brakes. The motor brakes are located on the non-driven end of the motor and the emergency brakes are mounted on a lower speed shaft in the drive train. All of the brakes are located on the high speed end of the differential which is not desirable because a failure in any component on the low speed side of the differential could result in loss of span control.

Each bridge is equipped with an auxiliary drive. The auxiliary drive is powered by an internal combustion engine that drives a gear train that engages with the normal drive via a reversing clutch.

The machinery for the highway bridge is significantly larger than the railroad bridge and is driven by two 75 horsepower motors compared to two 37 horsepower motors for the railroad bridge.

The 2008 inspection report identified numerous deficiencies and provided recommendations to allow for reliable service in the long term (5-10 years). The report also recommended that strong consideration be given to replacing the span drive machinery with modern machinery to improve system efficiency and reliability, reduce the risk of injury to maintenance personnel and to reduce maintenance and operating costs.

Our analysis of the machinery included determination of the required motor horsepower to operate the bridge per the CHBDC requirements and a limited analysis of the machinery per the CHBDC requirements.

The highway bridge requires 109 horsepower to operate at the current speed under CHBDC loading conditions. The bridge is powered by two 75 horsepower motors which provide 138% of the required capacity.

The railroad bridge requires 84 horsepower to operate at the current speed under CHBDC loading conditions. The bridge is powered by two 37 horsepower motors which provide 88% of the required capacity. Therefore the railroad bridge does not have sufficient power per the CHBDC.

The capacity of the span drive gears was checked versus the installed motors per the requirements of the CHBDC. Our analysis indicates that the P2/G2 gears on both bridges and the P4/G4 gears on the highway bridge are overloaded. The maximum overload is 33% at G4 on the highway bridge. Calculated and allowable gear tooth loads for both bridges are provided in Tables 3 and 4 below.

HIGHWAY BRIDGE GEARING			
Gear ID	Calculated Gear Tooth Load (lbs)	Capacity per CHBDC (lbs)	% Capacity
P1	83,017	91,488	91%
Rack	83,017	85,243	97%
P2	31,267	26,309	119%
G2	31,267	27,585	113%
P3	17,810	18,338	97%
G3	17,810	19,614	91%
P4	3,425	2,743	125%
G4	3,425	2,568	133%

Table 3. Highway Bridge Gear Loading. Highlighted values indicate an overload condition.

RAILROAD BRIDGE GEARING			
Gear ID	Calculated Gear Tooth Load (lbs)	Capacity per CHBDC (lbs)	% Capacity
P1	41,834	53,483	78%
Rack	41,834	49,900	84%
P2	15,644	14,434	108%
G2	15,644	15,286	102%
P3	8,402	10,058	84%
G3	8,402	10,651	79%
P4	1,805	2,963	61%
G4	1,805	2,796	65%

Table 4. Railroad Bridge Gear Loading. Highlighted values indicate an overload condition.

The increased span weight due to the proposed rehabilitation has a negligible effect on the required capacity of the span drive motors. This is because the increase in weight only affects friction and inertial loads which are relatively small components of the total force required to size the span drive motors.

The reported condition of the span drive machinery per the 2008 report combined with undersized motors on the railroad bridge and overstressed gears on both bridges provides justification to replace the span drive machinery as part of a proposed rehabilitation. The cost of replacing the span drive machinery on both bridges is included in the cost estimates found near the end of this report.

New span drive machinery will result in a reliable, safe and efficient mechanical system that will require far less maintenance than the existing system. All new machinery should be designed to meet the current requirements of the CHBDC. Although the capacity of the machinery will be increased to meet current CHBDC standards, because of the availability of better materials and designs, it is anticipated that the new span drive machinery arrangement can be fit within the current machinery envelope dimensions. Figure 2 in the Appendix depicts one possible machinery arrangement.

Span Lock Machinery

Each bridge has two span locks. The locking mechanism consists of a lock bar supported in a roller assembly that is mounted in the bottom cord of each truss at the toe end of the bridge. Each lock bar engages a receiver that is mounted on the channel side of the live load support casting. The lock bars are driven by an electric motor through a series of gears, bearings, shafts, levers, and links. The low speed machinery shaft extends across the bridge to drive the lock bar on the opposite side of the bridge.

This machinery was reported to be in fair condition in the 2008 inspection report. Only minor deficiencies were noted and the machinery operated satisfactorily during the inspection.

The CHBDC requires span locks to be designed for all loading conditions. In the case of the Johnson Street Bridge the seismic event loading is the most severe loading condition. This load is 1,100 kN applied vertically. The existing locks are significantly undersized for this loading condition and the application of this load will result in failure of the span locks.

Replacement of the span locks is required as part of the rehabilitation. The cost of replacing the span locks on both bridges is included in the cost estimates found near the end of this report.

Electrical Systems

The 2008 inspection report concluded the following: The condition of all electrical systems is in overall fair to poor condition at both the highway and railroad bridges. The equipment has degraded over the years and has not had any recent significant upgrades or rehabilitations. Most of the equipment is obsolete and nearing the end of its useful service life. Failures of various electrical components of the bridge are likely in the short term and will result in delays of the needed repairs due to inaccessibility of replacement parts.

Based on this conclusion, the entire electrical power and control installation is in need of replacement as part of the bridge rehabilitation. None of the existing electrical installation is salvageable. The cost of replacing the entire electrical system for both bridges is included in the cost estimates near the end of this report.

The new electrical systems should be designed to meet the requirements of the CHBDC and all applicable codes and regulations. Consideration should be given to providing redundancy in the design of all systems and including a standby generator for back up power to ensure a high degree of system reliability. Items such a system diagnostics, remote monitoring, and a surveillance system should also be considered.

Cost Estimates

Cost estimates for the required work were prepared based on historical cost for similar work on other movable bridges. The costs include replacement of mechanical machinery and electrical systems associated with the highway and railroad bridges as indicated below. These costs are in 2010 dollars and are budgetary in nature.

Costs are provided based on the three options previously provided with regard to the span support machinery. These options are:

1. Do not inspect or replace the span support bearings.
2. Inspect the span support bearings to the extent possible and base the rehabilitation effort on the results of the inspection.
3. Replace the span support bearings.

Options 1 and 2 are grouped together because the potential cost savings for Option 2 are only valid if the bearings are found to be in good condition. If Option 2 is pursued and the bearings are found to require rehabilitation, Option 3 is the applicable cost. Each option includes complete replacement of the electrical systems, replacement of the span drive machinery, and replacement of the span lock machinery.

Option 1 & Option 2 Cost Rehabilitation without Addressing Span Support Bearings	
Item	**Total Cost**
Span Drive (no racks)	$ 2,200,000
Rack, bogey wheel assembly and pin connection	$ 800,000
Span Lock Machinery	$ 500,000
Live Load Shoe Adjustment	$ 80,000
Balance Bascule Leaves	$ 250,000
Replace Electrical	$ 2,200,000
Option 1 Total	**$ 6,030,000**

Option 3 Cost Rehabilitation with Replacement of Span Support Bearings	
Item	**Total Cost**
Span Drive (no racks)	$ 2,200,000
Rack, bogey wheel assembly and pin connection	$ 800,000
Jack CWT	$ 3,000,000
Jack Span	$ 800,000
CWT Trunnion Bearings	$ 2,000,000
Heel Trunnion Bearings	$ 800,000
Link Pins and Bearings	$ 1,000,000
Field Machining	$ 240,000
Span Lock Machinery	$ 500,000
Live Load Shoe Adjustment	$ 80,000
Balance Bascule Leaves	$ 250,000
Replace Electrical	$ 2,200,000
Option 3 Total	**$ 13,870,000**

APPENDIX

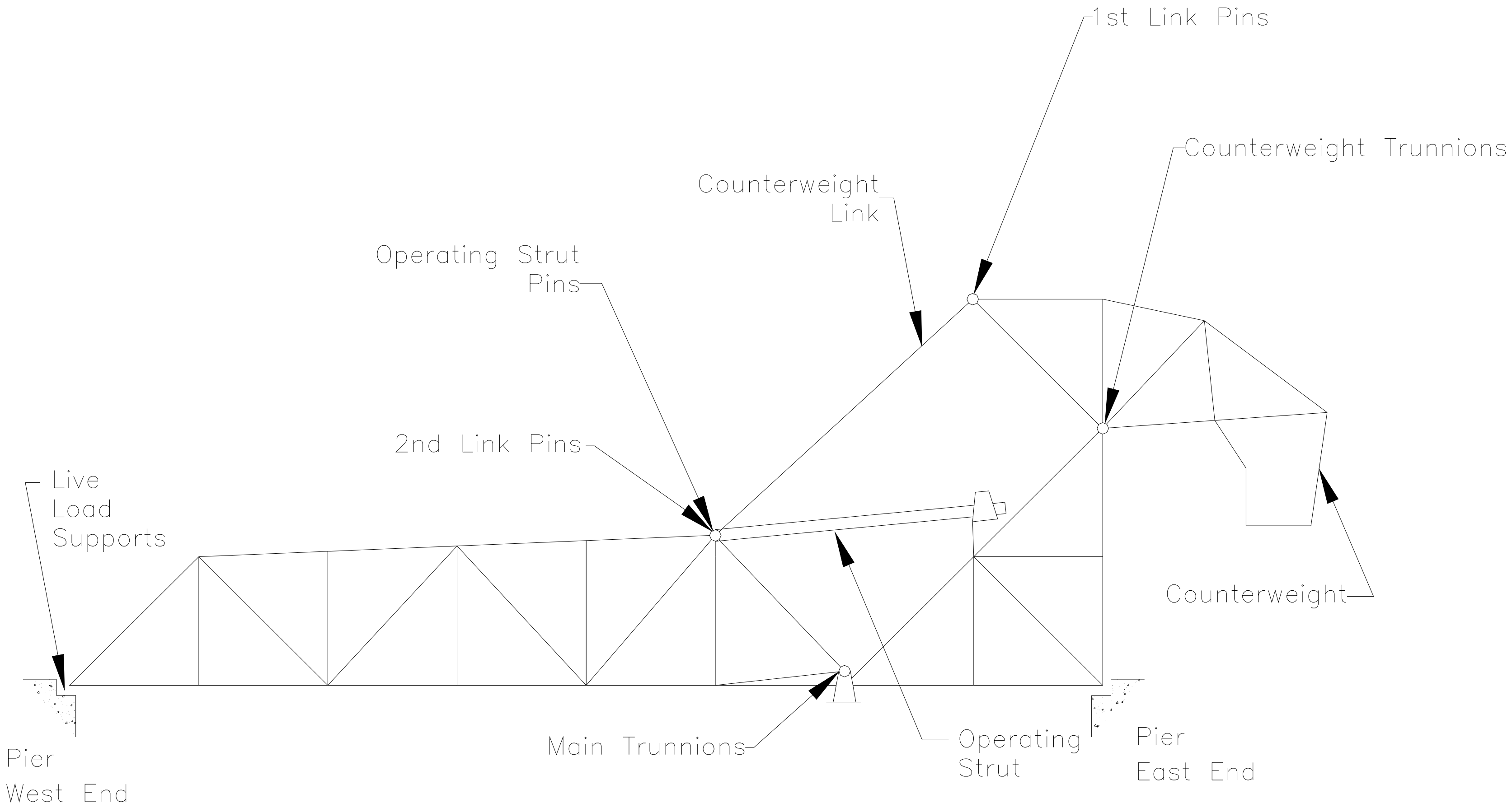

Figure 1. Span Support Machinery

Project:
Johnson Street Bridge
Machinery
Rehabilitation Feasibility

Prepared by:
Stafford Bandlow Engineering, Inc.

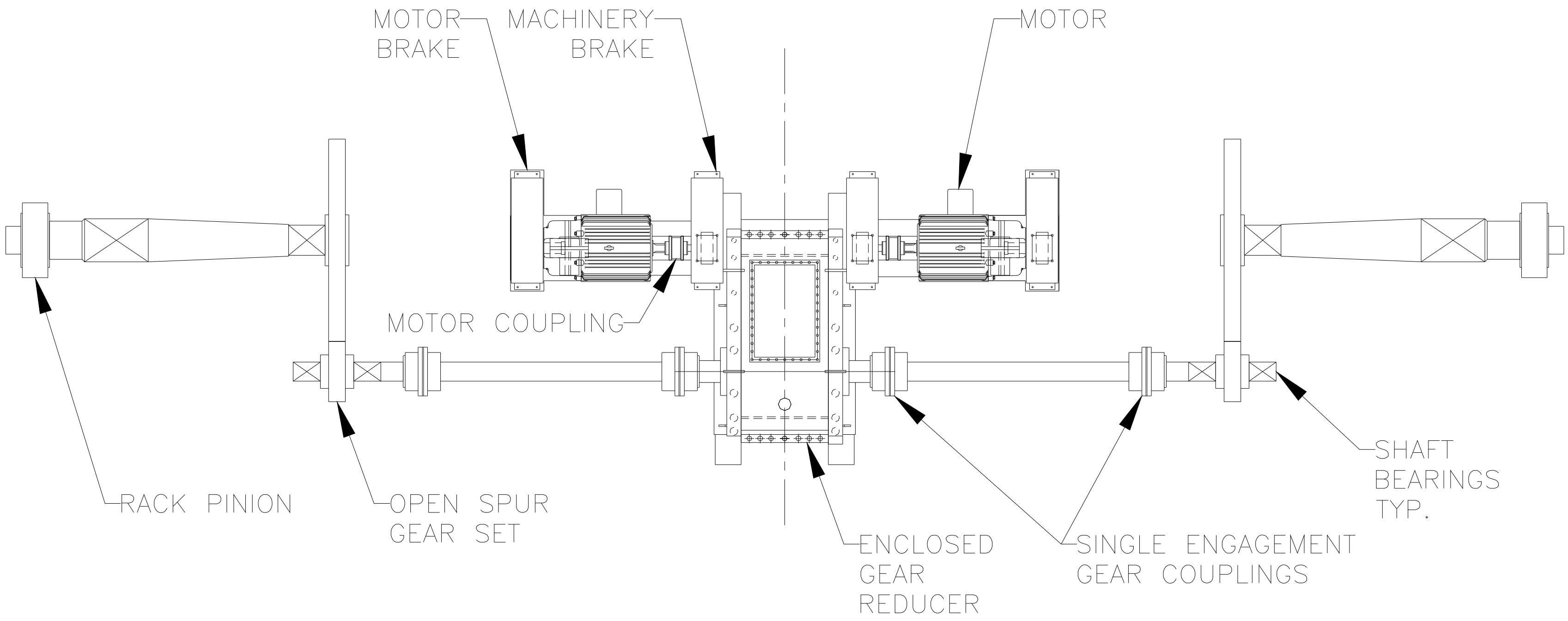

Figure 2. Possible Arrangement for Span Drive Machinery

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