Black Rock Lock
Bearing Replacement

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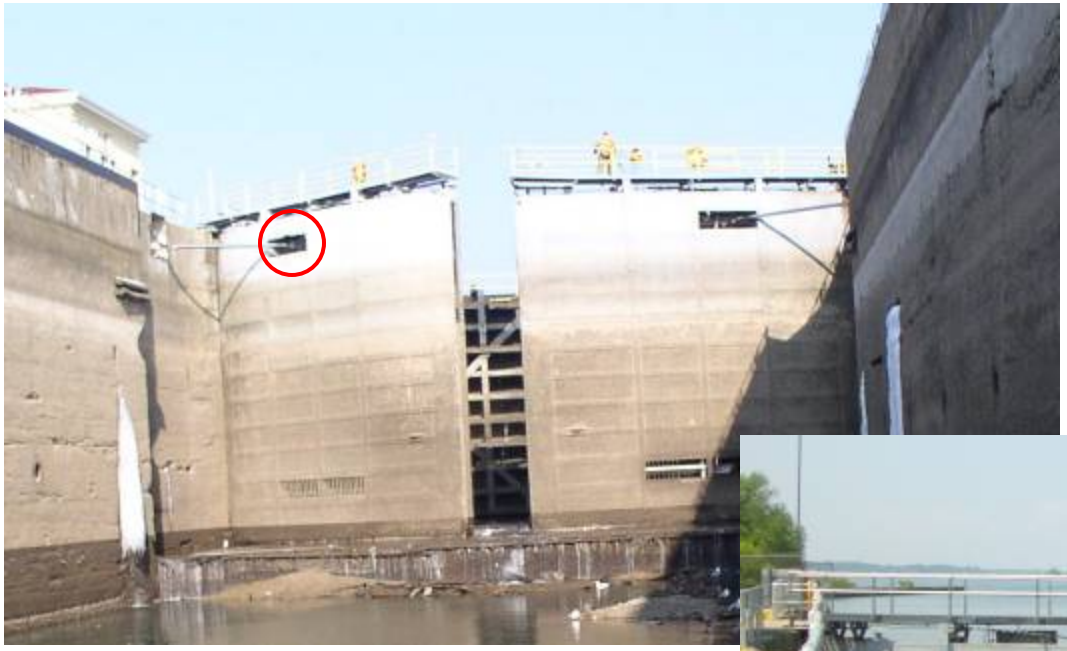
Miter Gate Hydraulic Cylinder Connection Pin



Problem

4” diameter clevis pin has been slowly working its way out over the past several years. Pin was only held in place by force fits.

Rod end eye with spherical bearing inside. Can see the slight horizontal rotation/tilt. Bottom cotter pin has been destroyed.

Clevis bracket

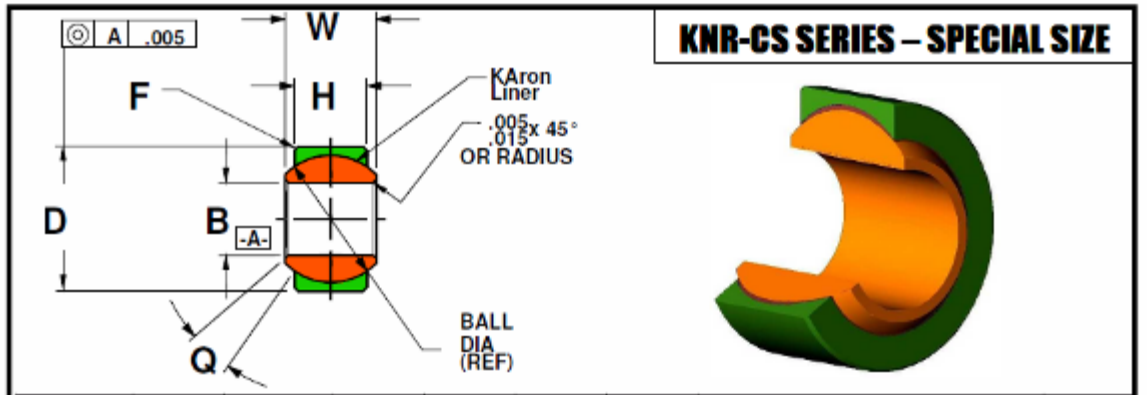
In-House Replacement Attempt

- This is the old identical assembly which was removed in the late 90's and has been exposed outdoors for several years. Attempt at pressing out with 20 tons of force was unsuccessful, which was the limit of the lock's maintenance capabilities.

SOW Requirements

- New 4” pin shall be a 4XX series stainless steel with min. RC40 hardness and min. surface finish of RA16.
- Pin shall have FN2 medium force fit to the clevis bracket and FN5 force fit to clevis eye to reduce fretting.
- In addition, keeper plates will be installed on both ends of the pin to prevent future pin slippage along the longitudinal axis.

KAron Lined Spherical Bearing



	B	D	W	H	Q°	F	LOAD RATINGS ARE CALCULATED FOR KAron "V"			
BEARING PART NUMBER	BORE DIA. +.0000 -.0005	OUTSIDE DIA. +.0000 -.0005	BALL WIDTH +.000 -.005	RACE WIDTH +.010 -.000	MIS-ALIGN-MENT ANGLE	MIN. CHAM. 45°	RADIAL LIMIT STATIC LOAD (LBS.)	RADIAL ULTIMATE STATIC LOAD (LBS.)	RADIAL DYNAMIC LOAD RATING (LBS.)	BALL DIA. (REF.)
KNR64-CS	4.0000*	6.2500**	3.500	3.000	5°	0.032	932938	1399406	424063	5.750

- KAron liner is maintenance free, self lubricating. The liner is homogeneous in nature, consisting of resin, PTFE, and other special fillers.
  - No interconnecting fibers that can provide a moisture path to the bonding substrate, which would promote corrosion.
- Liner thickness typically ranges between 0.010 to 0.015 inches.
- The inner bore will also be coated in the event there is movement between the pin and bore.

Contract Framework

- As this is the only connection permitting controlled gate movement, contractor must secure gate in fully recessed position when pin is removed.
  - Low force required in order to restrain movement since little horizontal load when gate is in pocket
  - Workers can enter gate pocket without the need for a PFD or fall protection
- Lump sum LPTA contract includes performance requirements to no more than a single day of lock downtime per bearing.
- 1 year warranty
- Awarded price per gate was approximately $8,000.

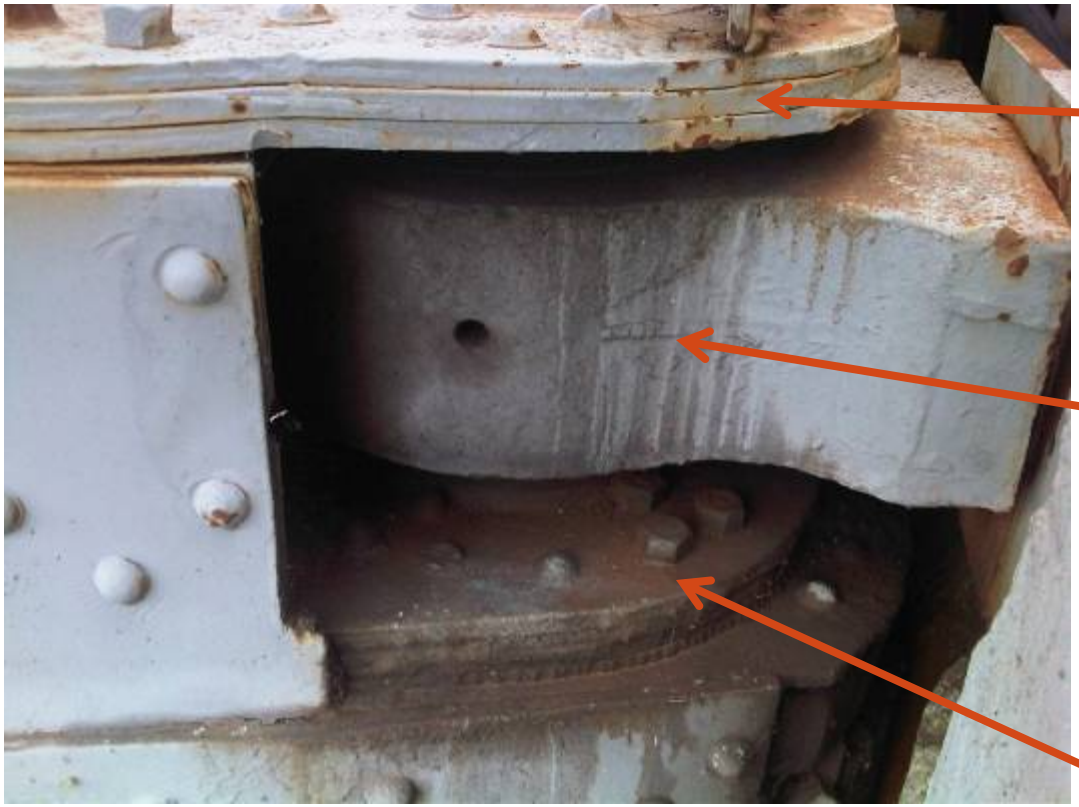
Miter Gate Gudgeon Bearing

2 points of gate connection to concrete lockwall which permit rotation:

Gudgeon at top

Pintle at bottom

Gudgeon Bearing

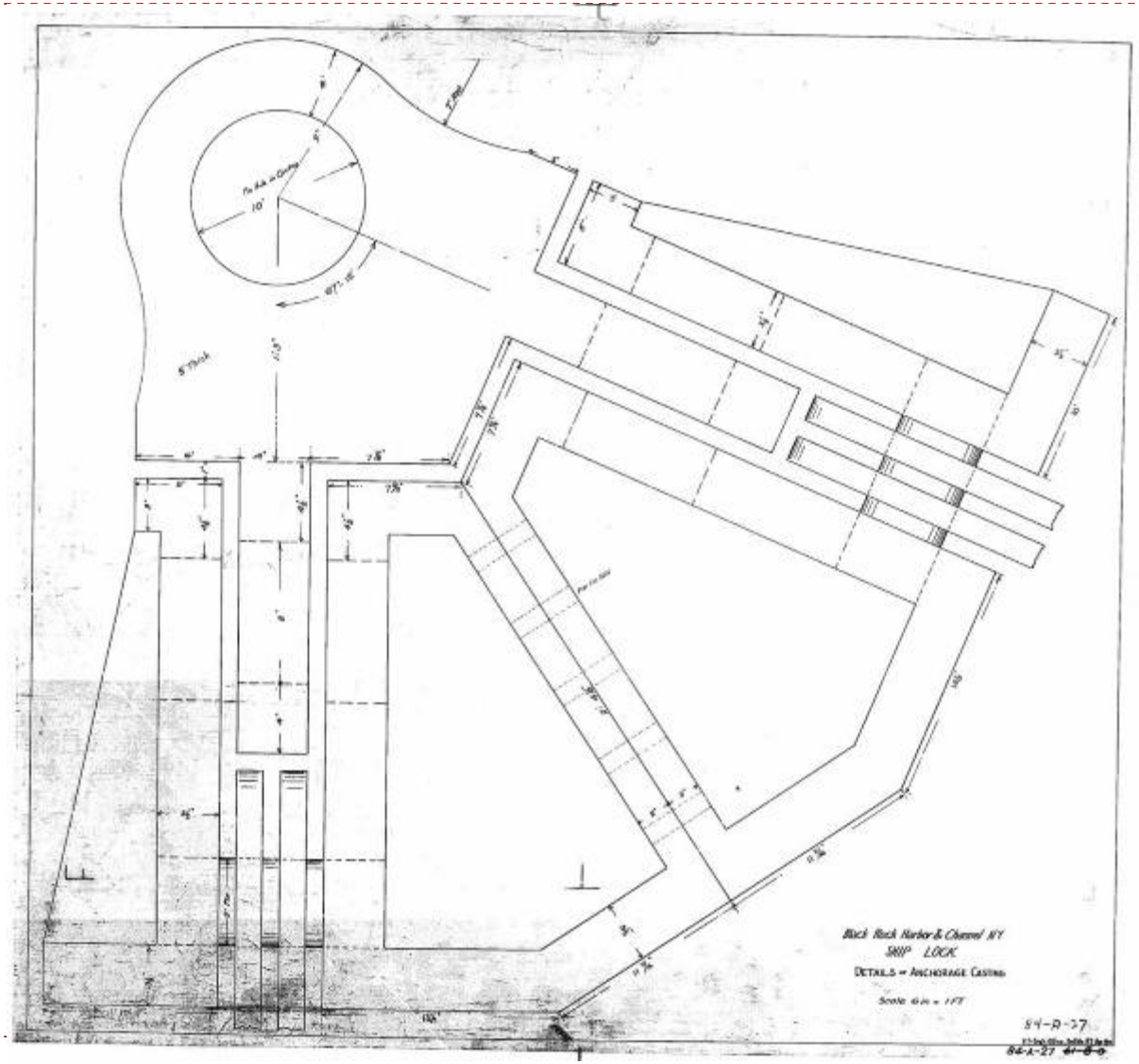


Top plate of the lock gate. This piece is 3 cast iron plates riveted together and secures the upper portion of the hinge pin. The pin is welded to this plate.

Casting that houses the bearing. This is connected to the tie bars. Bearing is a TRAXL type bearing, i.e. bronze shell with a thin layer of low friction polymer in the inner bore. Maintenance free, requires no grease.

Bottom plate of the lock gate. This piece is 3 iron plates riveted together and secures the lower portion of the hinge pin. The pin has a slip fit into this plate.

Anchorage Construction Drawing



Anchorage Casting

Casting that houses the bearing. This is connected to the tie bars by way of intermediate castings

Casting “ears” that connect to split castings which transmit load to tie bars embedded in concrete

Tie bars transmit load to concrete lockwall

Problem

- The lower east bearing was replaced in Spring 1993.
- Has been noisy for the past few years, generally during hot weather. (originally noted in the 2005 PI)
- Inspection had not indicated a problem, however we have continued to monitor this gate.
- Recently, shavings of bronze have been discovered below the bearing. This indicates that the low friction liner has worn away from the bronze shell that backs the liner. (Traxl type bearing)

Interim Measures

- After consultation with the Hydropower Center, proponents of the Lubrication of Mechanical Equipment PROSPECT course, we have selected an extreme pressure lubricant that can be sprayed into the bearing/pin interface area
- We have lubricated the lower east bearing with the above product for the remainder of the CY12 operating season
  - Bearing noise has decreased

Long Term Measures

- Investigate cause of failure
  - Inspect bearings
  - Survey motion of lock gates to determine if alignment issues are a factor
- Plan for replacement of bearing
  - Review prior replacement work
  - Determine options, select preferred repair scheme and contract for repairs to take place in the spring (advertise February, on-site in April)

Survey/Inspection

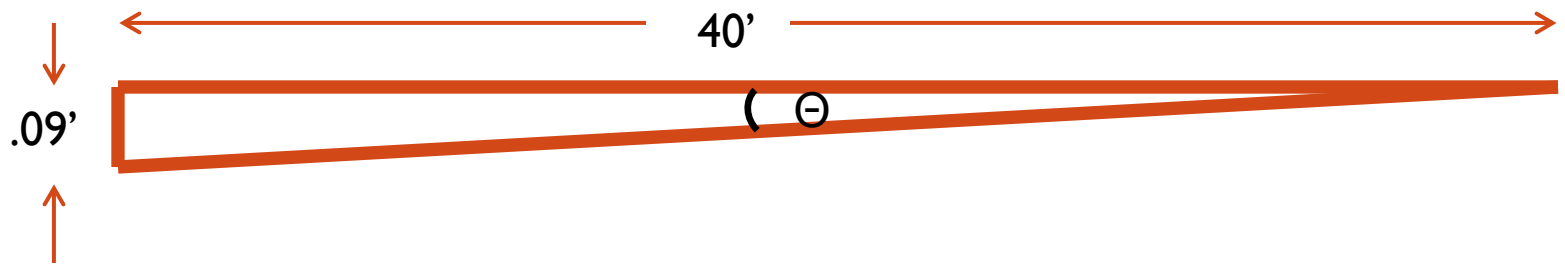
- Survey lock gates to see if misalignment occurs when water pressure from high pool moves gates into final miter position
  - 5’ water differential
- Inspect other miter gate bearings
- Review notes from other bearing replacements

Gate Survey

- Initial survey was performed in order to see if the miter end of the gate moves in a vertical direction as the lock goes from high to low pool.
- Lower East gate was surveyed on 31 Oct
  - At high pool the miter end of the gate was 0.09 feet higher than at low pool.

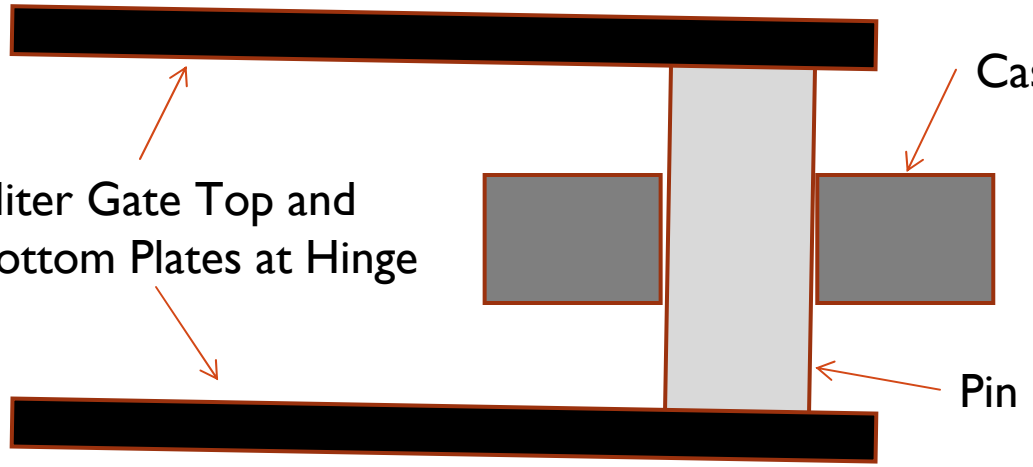
Gate Misalignment

0.09 feet over a distance of 40 feet equates to an angular misalignment of 0.13 degrees



$\Theta = \tan^{-1}(0.09/40) = 0.13^{\circ}$

Pin Misalignment



This depiction is a 1 degree misalignment, visible to the naked eye. Actual misalignment is about 1/8 of this.

- Gate misalignment translates to pin misalignment
  - Pin "cocked" by 0.018"
  - Minimum running clearance recommended for 8" shaft by Thordon: 0.010"
  - Relatively high thermal expansion coefficient, temperature increase = clearance decrease
  - High ambient temp related to bearing noise as result of gate deformation from iron heating up

Corrective Actions for Misalignment

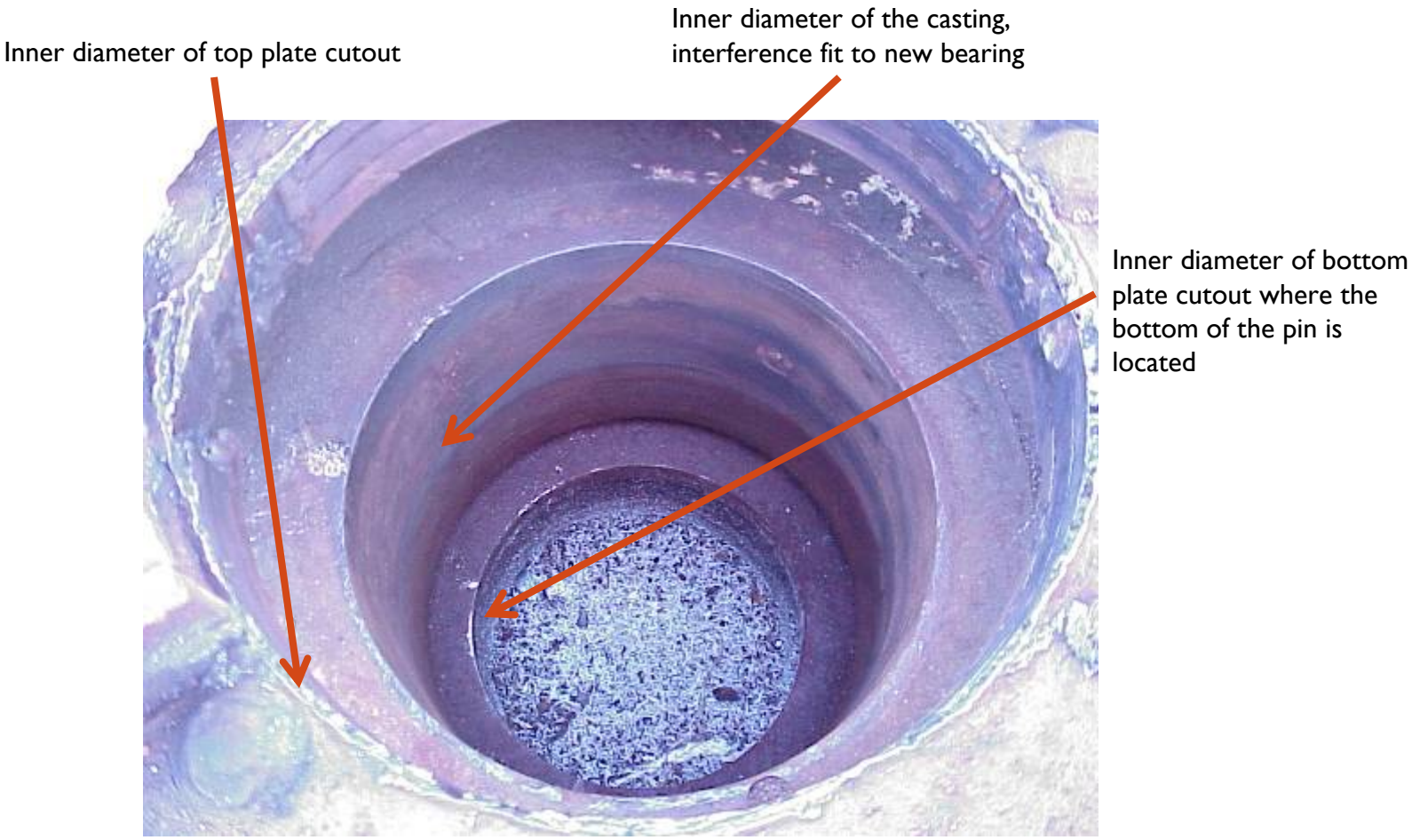
- Use casting wedges to raise level of gates so that sag at low pool is minimized and the gates stay closer to the alignment they were in when the bearing and pin was installed (work done during high pool).
- Use a more misalignment compliant bearing
  - Provide larger running clearance in the bearing
  - Use a spherical type bearing which allows slight tilt of the pin

General Repair Scheme

- Cut out the top plate enough to gain access to the bearing.
- Remove the cut out portion of the top plate and pin which is welded to this plate.
- Remove the old bearing.
- Perform finish machining of the new bearing to match the bore of the casting, freeze it and install the bearing to an interference fit.
- Install new pin and top plate insert, weld in place.

Removal of Top Plate and Pin

Ready for New Bearing



Insertion of Pin to Bearing and Installation of New Top Plate Insert

New pin is type 316L stainless steel, 18” long, nominally 8” in diameter.

Pin is a slip fit to the bottom plate, welded to the top plate insert.

Gate Support During Repairs

- Due to the upper hinge pin being removed to replace the bearing, the gate will be disconnected and must be supported in place.
- Prior practice was to have the Derrickboat Simonsen on site to hold the gate and lift it if necessary. However, the Simonsen has been excessed and is no longer available. LRD currently has no floating crane capability to lift the weight of the gate.
- Alternative is to depend on water pressure from 5' pool differential to hold the gate in place. Approximately 18 tons of force would be pressing the gate against the miter to hold it in place during repairs. Would need to take precautions to keep the water level in the chamber at high pool during repairs. e.g. upper gates fully open

New Bearing Options

1) Replace with new Traxl bearing. Traxl is a bronze backing with a thin coating of low friction polymer. This is what is currently installed at the failing bearing location (lower east gate). Does not require lubrication. This is what is currently also in place at the lower west gate. The lower west bearing was replaced in 1999 and is still in service.
2) Replace with new bearing of solid low friction polymer which does not require lubrication.
3) Replace with new bronze bearing. This is what is currently in place at both upper lock gates, last replaced 20+ years ago. Requires lubrication.
4) Replace with new spherical bearing which can compensate for vertical gate tilt. May or may not require lubrication.

Option 1, New Traxl Bearing

- Is what is currently in place and has failed on the lower east gate but has been in service on the lower west gate since 1999.
- Requires good pin and bearing alignment
- Moderate cost of the bearing
- Approximate 6 week lead time

Option 2, New Tube Bearing of Low Friction Material

- Able to tolerate moderate misalignment.
- Low cost of bearing due to having the material on hand from prior bearing replacement. (was acquired as a back up plan in case the Traxl bearing experienced installation problems)
- Was installed previously on the lower west gate, failed when the bearing spun in the casting. However this may have been due to factors that can be compensated for. (tighter shrink fit, retaining screw through the casting)

Thordon HPSXL Material

- Thordon HPSXL (grey) is designed for higher pressure applications as the bearing component in HPSXL TRAXL bearings (HPSXL bonded in a metallic shell).
- Homogeneous material
- Maximum dynamic working pressure to 55.0 MPa (8,000 psi) in limited motion
- Lowest coefficient of friction (typically 0.06-0.12)
- Moderately abrasion resistant (lower abrasion resistance than XL or SXL)
- High resistance to shock loading and vibration

HPSXL Tube

We have a tube of the material on hand from the prior renewal of this bearing. It was a backup bearing in the event that there was difficulty in fitting the Traxl shell to the casting at the lower east gate. It is similar to the SXL tube that had been used for the lower west bearing and failed when the bearing spun in the casting.

Option 3, Replace with Bronze Plain Bearing

- Currently in use on upper operating gates for extended time.
- Requires good pin and bearing alignment.
- Moderate cost of new bearing.
- Requires periodic lubrication.

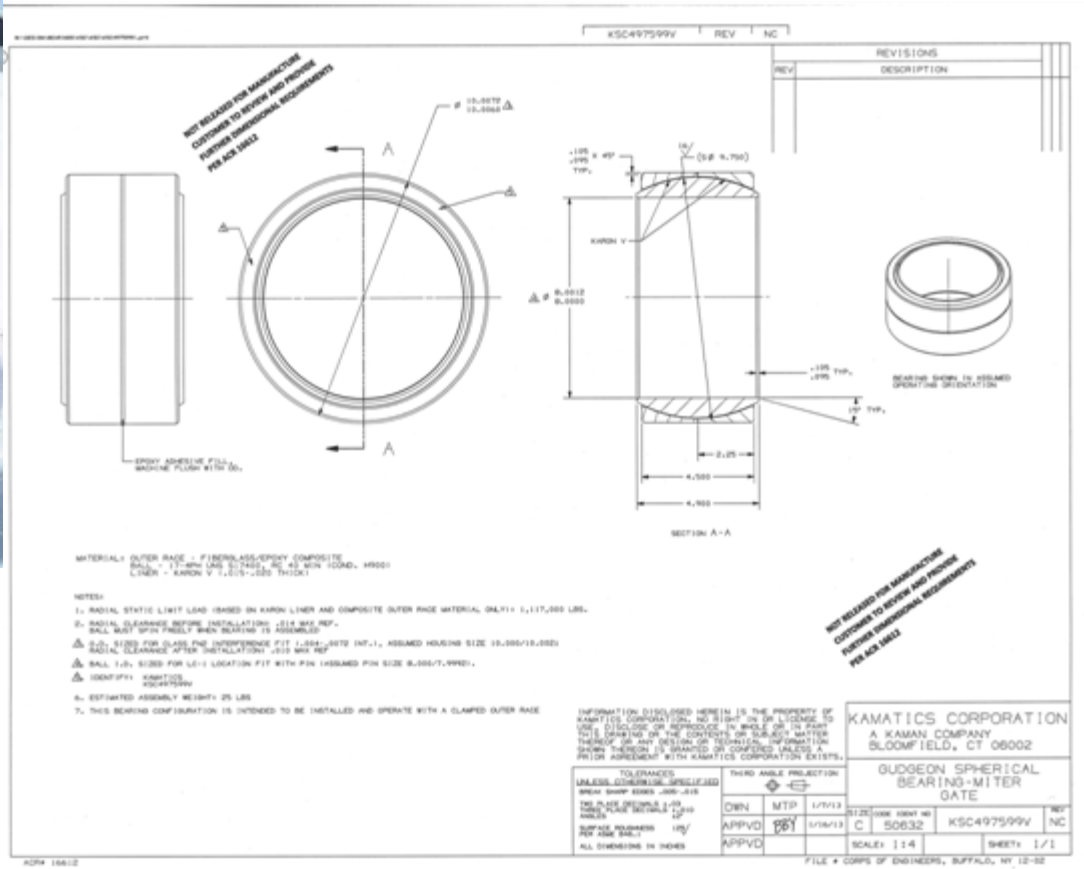
Option 4, Spherical Bearing

- No experience with this type of bearing in this application.
- Able to tolerate moderate misalignment.
- Higher cost due to more intricate construction.
- May or may not require lubrication. Preferred option would be a maintenance free bearing. One possibility would be to install a "permanently" sealed bearing. i.e. seals at the bottom and top of the casting and grease encasing the bearing.
- Standard products to fit 10" casting bore would require a smaller pin than is currently installed (6 ½" versus 8")
- Ballpark material/fabrication cost- $4,000

Smaller Diameter Pin Analysis

- Would require sleeving of the top and bottom plates to match new pin and sleeve in the casting to match the bearing
- Possible to step the top plate insert making future replacement work easier
- Stepping the bottom insert could be used to increase the supported length of the pin
- Analysis based on RBC Bearings model 8104-LSSQ (6 ½" pin, 4.875" tall bearing) indicates that deflection under load is acceptable but stress exceeds yield point stress of 316L steel, which is in place now.

Spherical Bearing



Initial Comparison

OPTION	COST	DEAL WITH MISALIGNMENT	RISK	RATING
1- Traxl	High (1)	Low (8)	Medium-Low (6)	1+8+6=15
2- Tube	Free (5)	Medium-High (14)	Medium (5)	5+14+5=24
3- Bronze	Medium (3)	Low (6)	Low (10)	3+6+10=19
4- Spherical	High (1)	High (20)	Medium (5)	1+20+5=26

Factors:
1) Cost: 1-5 with1 being high, 5 being free
2) Ability to deal with misalignment: 1-20 with1 being low ability and 20 being high
3) Risk: 1-10 with1being high risk, 10 being low risk

Note: Assumes that misalignment is highest factor followed by risk and then cost.

Follow up Survey

Gate		Total rise from low to high	Distance between readings	Tilt in degrees	Bore closure over 8" bearing length
Lower East	Quoin	0.006			
	Miter	0.095			
	delta	0.089	40.21	0.127	0.018
Lower West	Quoin	0.002			
	Miter	0.062			
	delta	0.06	40.23	0.085	0.012
Upper East	Quoin	0.001			
	Miter	0.023			
	delta	0.022	38.84	0.032	0.005
Upper West	Quoin	0.003			
	Miter	0.023			
	delta	0.02	38.53	0.030	0.004

all measurements in feet
data date 11/7/2012

- Greatest bore closures are on the lower gates with the biggest being on the gate experiencing bearing failure

Test of Casting Wedge Adjustment

- A test of the effect of taking the "lash" out of the anchorage system was performed on the lower gates.
- The gate casting wedges were "frozen" in place and could not be adjusted with the use of a hydraulic jack. However, shims were placed behind the wedges in order to take up system lash in both directions.
- The gates were then re-surveyed. The lower east gate differential was .047' (.089' previously), lower west was .039' (.060' previously)
  - Lowers bore closure to 0.008" and 0.007" respectively
- One anomaly is that previously the quoin end of the gates did not experience significant movement, but after the adjustments the lower east gate quoin moved upward by .026' when going from low to high pool and the lower east moved upward by .009'. However, both gates experienced less upward movement at the miter end thereby lowering the differential/misalignment between the low and high pool states.

Lessons Learned

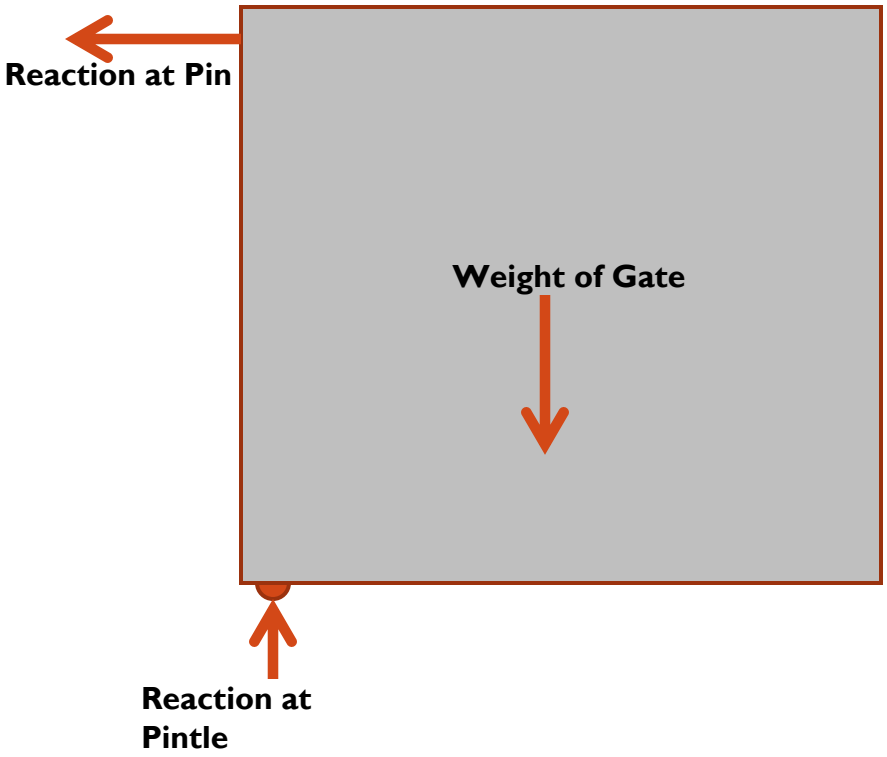
- Gates need to be adjusted so that they stay level throughout the range of travel. Otherwise there will be misalignment between the upper hinge pins and the bore of the bearings.
- Access to the pins and bearings is unfavorable, a scheme for better access in order to perform inspections and repairs would be beneficial.

Considerations

- New top plate closure to allow for easier future bearing replacements.
- Purchase spare bearing(s) in case of future failures and long lead times for production of replacement bearings.
- Same for purchase of spare pin(s).
- Line bore top and bottom plates and casting bore in order to insure concentricity.

Bearing Loading

- Weight of Gate approximately 80 tons
- Assume 40’ by 40’ gate
- Reaction at pintle equals weight of gate
- Reaction at pin equals ½ weight of gate
- Specify bearing for 40 ton load with appropriate safety factor for 20+ year service life
- 8” pin and 8” bearing height -> 1,250 psi bearing pressure
- 8” diameter hydraulic cylinder at 1,000 psi= 25 ton loading for gate movement



Contract Framework

- Purchase 4 bearings, enough for the entire lock
  - 40T load
  - 3,000 cycles/year x 20 years -> 60,000 cycles
- Field machine shop services
- Bid to be a combination of lump sum and hourly rates
  - Hourly rate for machining casting, top and bottom plates, etc due to unknown requirement
  - Lump sum for basic work items and materials
  - Options for new/spare pin(s)
  - Bearings will be government furnished due to long lead times


Questions?