HEAVY MOVABLE STRUCTURES, INC.
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Vertical Lift Bridge Seating Issues
Rt 1 & 9T Bridge over Hackensack River

Hammad Mumtaz, Ph.D.
Robert Algazi, P.E.
WSP, USA

Georgio Mavrakis, P.E.
Ulysses Wallace III
NJDOT, USA

SHERATON HOTEL
NEW ORLEANS, LA

Introduction

The Route 1&9T Bridge over Hackensack River is a tower drive vertical lift bridge, located in Jersey City in the County of Hudson, New Jersey. It is owned, operated, and maintained by the New Jersey Department of Transportation (NJDOT). The bridge was built circa 1954 and provides three (3) lanes of vehicular traffic and a sidewalk in both east and west bound directions. The bridge provides a 200'-0" horizontal clearance between the fenders and a 135'-0" vertical normal clearance for navigation when the lift span is fully raised.

Photo 1: Rt. 1&9T over the Hackensack River as viewed from the river.

Historically, the Route 1&9T Bridge over the Hackensack River has experienced continuing seating issues at the live load shoes for several years. Periodically, one of the live load shoes (typically at the southwest corner) would not completely seat on the strike plate preventing the full seated limit switch from triggering. A significant gap between the southwest live load shoe and the strike plate has been noted and on occasion measuring upward of ½ inch. It is believed that due to the gap at the live load shoes, the ropes at this corner slip over time due to the high truck volume on this roadway that tends to use the right lane for the eastbound travel.

Some interim work was attempted over the years to correct the seating; however, the condition persisted. This has led to operational issues effecting the reliability of opening the bridge to traffic after an opening. Extensive investigations were conducted by NJDOT and WSP's mechanical and structural engineers to determine the source of the issue and develop the repair solution.

In 2020, NJDOT included repair work to the live load shoes as a part of their Drawbridge Preventive Maintenance Contract. The contract repair plans were developed by WSP and were based on recent in-depth (NJDOT Type I) Mechanical Inspections. The selected Contractor Agate Construction Co. and Contractor's Engineer WJE were tasked with performing rope tensioning, live load shoe shimming, machinery indexing, and span balancing.

Initially, it appeared that the seating issues were corrected after completion of the 2020 Contract; however, the issues were later observed again. Further investigations were conducted determining additional repair work was necessary. This repair work was added into the next Drawbridge Preventive Maintenance Contract cycle.

Photo 2: Left - Live Load Shoe; Right - Live Load Shoe Fixed Pin

Bridge Overview

The lift span is operated in the normal drive mode by the 174HP, 550 RPM DC main electric motors. The motor in each machinery room is connected to the input shaft of the enclosed primary differential reducer. The primary reducer provides a single reduction between the main drive motor input and reducer output shafts. Under auxiliary drive conditions, the lift span is operated at a reduced speed in the “auxiliary” drive mode by the 50HP, 580 RPM AC electric auxiliary motors. In the “emergency” drive mode, the lift span is operated at a further reduced speed using the 10HP, 900 RPM AC emergency motors. Each span drive machinery assembly is equipped with two (2) sets of spring-set, thrustor released drum brakes; designated as the motor and machinery brakes.

A warp adjusting clutch and several transverse line shafts are connected via couplings from each primary reducer output shaft to an enclosed secondary reducer inside the sheave room at each corner. Each secondary differential reducer has a dual extended output shaft which is coupled to two integral pinion shafts. Each pinion drives a ring gear attached to the counterweight sheave. Each counterweight sheave supports eight (8), 2-1/8-inch diameter, 6 x 25 construction, improved plow steel ropes; for a total of sixty-four (64) counterweight wire ropes on the bridge.

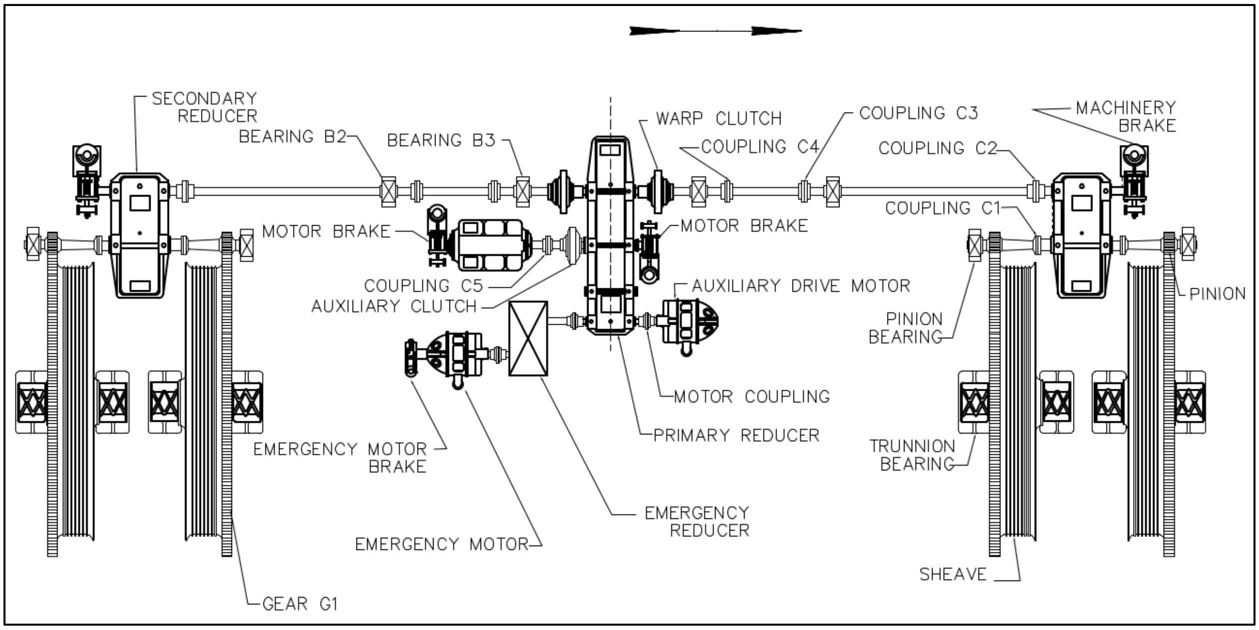


Figure 1 – Typical Operating Machinery Plan Layout

There are four live load bearings provided at the corners of the lift span below the road deck to transmit vehicular and imbalance loads from the lift span to the piers. The two (2) live load assemblies at the west end are the “Pin and Saddle” fixed type supports. The fixed live load supports are designed to maintain the position of the span in the longitudinal direction. The two live load supports at the east end of the bridge are “rocker” type supports and are designed to accommodate thermal expansion and contraction of the lift span.

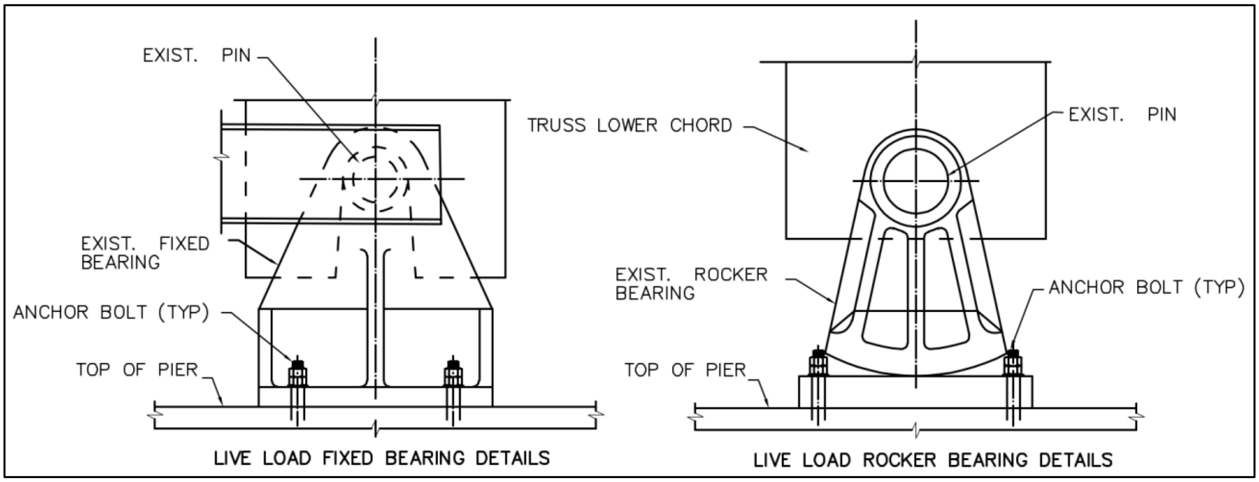


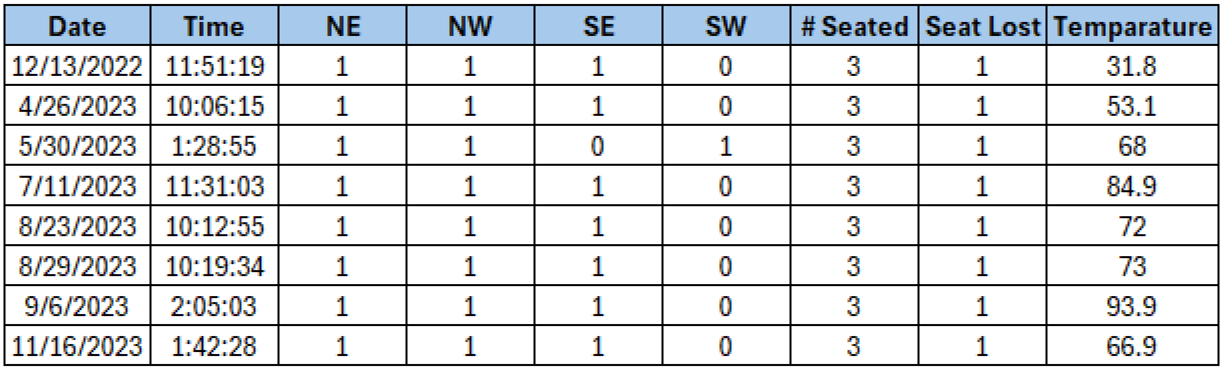
Figure 2 – Typical sketch of the Live load shoe. West side fixed (left) and East side expansion (right)

Preliminary Investigations

Several investigations were conducted by NJDOT and WSP engineers during the 2020 contract and later after into the cause of the live load seating issues. This includes investigations into several factors which can affect the bridge seating of a vertical lift bridge including bridge balance, seating elevations, machinery indexing, rope tensions, and thermal effects.

Live Load Shoe Seating Gap

Historic seating data was provided by NJDOT of incidents occurring over the course of a year. The majority of the time the southwest corner did not seat properly, with one instance of the southeast corner as well. The data suggests that the occurrences of the seating loss does not correlate with the temperature's changes ranging from 31 degrees F to 94 degrees F.



Date	Time	NE	NW	SE	SW	# Seated	Seat Lost	Temparature
12/13/2022	11:51:19	1	1	1	0	3	1	31.8
4/26/2023	10:06:15	1	1	1	0	3	1	53.1
5/30/2023	1:28:55	1	1	0	1	3	1	68
7/11/2023	11:31:03	1	1	1	0	3	1	84.9
8/23/2023	10:12:55	1	1	1	0	3	1	72
8/29/2023	10:19:34	1	1	1	0	3	1	73
9/6/2023	2:05:03	1	1	1	0	3	1	93.9
11/16/2023	1:42:28	1	1	1	0	3	1	66.9

Table 1: Log of seating issues

The gap at the southwest corner live load shoe has been observed to increases, causing the seated position of the corner to rise over time. Often the bridge instrumentation may indicate the bridge is seated when there remains a gap at the shoes. In this situation, the live load is supported by the wire ropes instead of being fully transferred through the bridge's seating mechanism.

SPR-1 (Red) plastigages were used to assess the clearance of the bridge's live load shoes during seating. Plastigages are set to a specific thickness such that when they are compressed under load it will correlate to a specific clearance. The gages were installed on the stationary component of the west live load shoe while the span was lifted (where feeler gages normally would not fit).

The plastigages were installed while the span was open and initial conditions of the plastigages were recorded. The span was fully seated and then partially opened to allow for examination. Deformation of the plastigages was recorded and measured with the provided scale. The following table summarizes the live load shoe clearances as measured on 12/13/23 and 1/03/24 during the time of testing:

WEST	**Live Load Shoe Location**	**Measured Clearance [Inches]**
	Northwest – North End	0.006
	Northwest – South End	≈0.006
	Southwest – North End	No Contact
	Southwest – South End	No Contact

Table 2: Clearance measurement using plastigages

It is evident from the observations and measurements that the clearance at the southwest corner live load shoe has been increasing over time. There is a clear indication of the bridge being seated when there actually remains a gap at the shoe. The use of plastigages provided a method to directly assess the clearance and emphasize the importance for close monitoring of the bridge seating mechanism.

Photo 3: No contact on southwest live load shoe (left) & minor contact on the northwest live load shoe

2020 Seating Adjustments

During the 2020 Contract, it was made a priority to shim the live load shoe assemblies before any other work began. The live load shoe itself is built into the truss of the lift span making the strike plate the only adjustable component. Semi-circular shims on the pin were not deemed feasible as they could impede the proper seating of the live load shoe saddle and prevent intended rotation at the pin; therefore, it was agreed to add shims under the strike plate, atop the concrete pier.

Photo 4: Left - Live Load Shoe Fixed Pin; Right - Live Load Shoe Saddle

While loosening the live load shoe strike plate anchor bolts so it could be lifted to insert shims, one of the anchor bolts sheared, likely due to excessive torque applied by the work crew. The shearing occurred at the surface of the live load shoe base plate preventing the bolt to be reused; however, the bolt portion left in place at this location does provide some capacity for lateral loads.

Photo 5: Live Load Shoe Anchor Bolt Sheared

A live load shoe repair detail to supplement the broken anchor bolt additional anchorage was provided by the Contractor. The repair consists of a new channel mounted off a stiffener of the live load shoe strike plate that is anchored to the concrete with a new anchor bolt. The existing failed anchor remains and was caulked and painted to prevent corrosion.

Machinery Index and Rope Slippage

Machinery index is the alignment and sequencing of a gear train with multiple output pinion gears. Ideally, gear trains have both output pinions operating simultaneously (pinion gears engage the mating main drive rack gears at the same time). Indexing is the process of adjusting machinery components driven by a common set of motors to improve load sharing, span seating and smoother, better controlled operation. It is an iterative process because the index is affected by several elements including main pinion gear set cross-indexing, span seating and live load shoe clearances, and the transverse imbalance.

The machinery is considered cross-indexed where one pinion gear set is in bridge closing face contact and the opposite pinion gear set is in bridge opening face contact. Ideally both pinion gear sets should have closing face contact with the bridge in the closed position and a span-heavy condition. This ensures the pinion sets are synchronized and helps even out load sharing.

Observations during testing and inspection indicate that the span drive machinery indexing would tend to change over time. This would be most noticeable after any cross-indexing was corrected. The wire ropes would slip on the sheaves after the first bridge lift following indexing corrections. This was confirmed by observing alignment paint markings on the counterweight wire ropes and sheave before and after test lifts. The SW corner counterweight wire ropes would slip up, meaning that the SW live load shoe would also seat a higher similar amount. This would continue until the machinery was completely cross indexed again. Once cross indexed, the rope slippage would slow down but not completely disappear. It would continue to slip until the bridge would no longer seat properly. Since the machinery would continue to become cross indexed over time, it is believed that the index is a symptom of the overall issue and not necessarily a cause; therefore, correcting the seating issue would also correct the indexing issue.

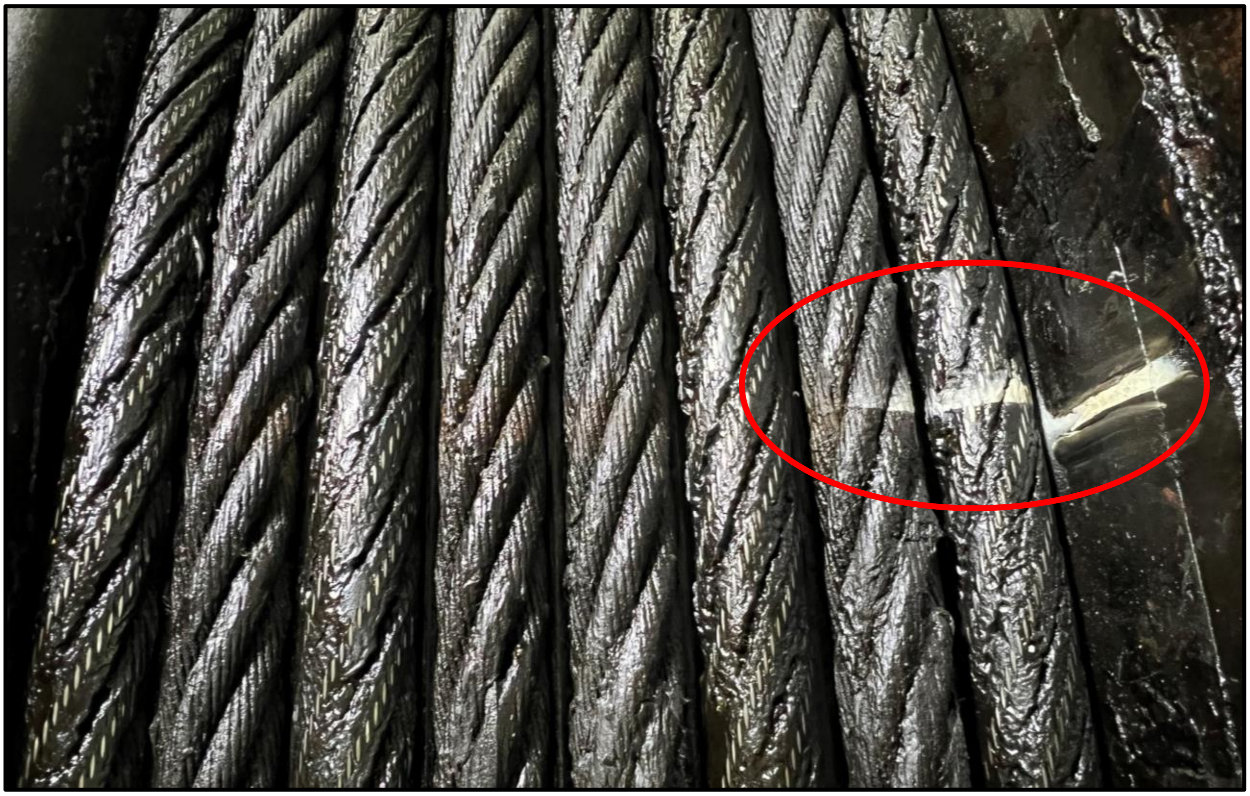


Photo 1: White Markings on the Wire Rope and Sheaves Indicating Rope Slippage

Testing

In addition to the above investigations, extensive testing was performed including span balance testing, rope tension measurements, seated live load measurements, machinery indexing adjustments, and bridge surveying. These tests were performed prior to the repair work, as a part of the repair work, and again after the repair work after the issue persisted.

Span Balance Measurements

The bridge balance was measured several times since 2019 as a part of the design and construction work. Testing was performed by WSP, WJE, and Gresham Consulting at various times. All balance testing was performed via the dynamic strain gage method. The average of multiple tests for each cycle is summarized below. Minor weight adjustments were made in 2021 as a part of the repair contract (also shown below).

Historic Balance Measurement	West		East		Total
	NW	SW*	NE	SE	
Imbalance Averages	(lbs)	(lbs)	(lbs)	(lbs)	(lbs)
2019 (Gresham)	8,880	11,505	11,234	8,285	39,904
2020 (WJE)	7,054	6,790	6,718	4,922	25,484
2021 Weight Adjustments	0	0	-846	1,659	N/A
2021 (WJE)	4,318	7,999	8,748	4,524	25,589
2023 (WSP)	7,548	10,043	10,032	8,106	35,729

Table 3: Imbalance measurements

There are notable variations in the actual loading as shown in the 2020/2021 total measured imbalance. These variations have been attributed to difference in the data analysis methods between testing companies.

Although variations are present, all tests consistently suggest the bridge was slightly heavier in the SW and NE corners. This directly contradicts observations that the SW leaf tends to raise (seat higher) over time. A more toe heavy imbalance at this corner would suggest that this corner would want to seat lower over time, or that the ropes would slip causing this corner to drop; however, this is not the case.

It is important to note that the imbalance measurements are affected by the indexing arrangement of the machinery. As previously noted, the wire ropes would slip after any indexing work. Because the machinery is in a cross-indexed condition normally, the machinery is typically reindexed before any strain gage testing in order to zero out the strain gages (a process where the zero-torque condition is established by manually rotating the pinion gear until it is not in contact with the mating gear and therefore no torque is built up in the strain gages). This results in notable variations in test runs.

Below is an example of the variations from test run to test run taken from the post balance adjustment testing in 2021. These variations from run to run make it difficult to verify the actual imbalance at each corner.

2021 Test Results			
Run	**NW Corner**	**SW Corner**	**Transverse**
1	5,199	6,914	1,715
2	4,510	7,913	3,403
3	3,777	8,633	4,856
4	3,787	8,535	4,748

Table 4: Variation in the Imbalance measurements

Rope Tension Comparison

The above balance measurements were compared to the 2023 recent counterweight wire rope tension measurements (shown below). Theoretically, the difference in total group rope tension from corner to corner should corelate to the span balance measurements; however, there is a notable increase in rope tension measured at the Southwest corner compared to all other corners. It is believed that the additional load seen on the Southwest rope group tension is from the traffic live load, since this corner is not fully seated. This bridge sees particularly heavy truck traffic and structural analysis indicated the theoretical live load seen at each corner can reach up to 200 kips; therefore, the additional loading recorded appears to be from the traffic. It is important to note that the Northwest corner rope group tension is also higher than the east groups. This suggests that the additional live load on the Southwest corner is also distributed through the truss and over to the Northwest shoe.

Rope Tension Results	**NW**	**SW***	**NE**	**SE**
	(kip)	**(kip)**	**(kip)**	**(kip)**
2021	688.2	720.0	675.9	670.9
Diff from Smallest	17.30	49.10	5.00	0.00
Diff Btw differential Tension and Imbalance	16.81	46.48	2.28	0.00

Table 5: *Data taken after Rope Tension Adjustments Completed in 2021.*

Movement Under Live Load

During the 2023 strain gage testing and after one complete test lift, the strain gage testing equipment was left on to record the torques in the west span drive machinery under live load traffic. While traffic was on the bridge, movement/torque was observed at the Southwest corner but not at the Northwest corner. This corresponds to the fact that the northwest corner was fully seated, and the wire ropes should not see the live load. This also confirms the southwest corner was not fully seated and the wire ropes will see the live load. Traffic on the southwest corner would increase the seating load seen on the machinery, as if the live load was pushing that corner down. Similarly, traffic on the northeast (opposite) corner would decrease the seating load seen on the machinery, as if the span was twisting resulting in uplift. Below are the raw recorded data for comparison.

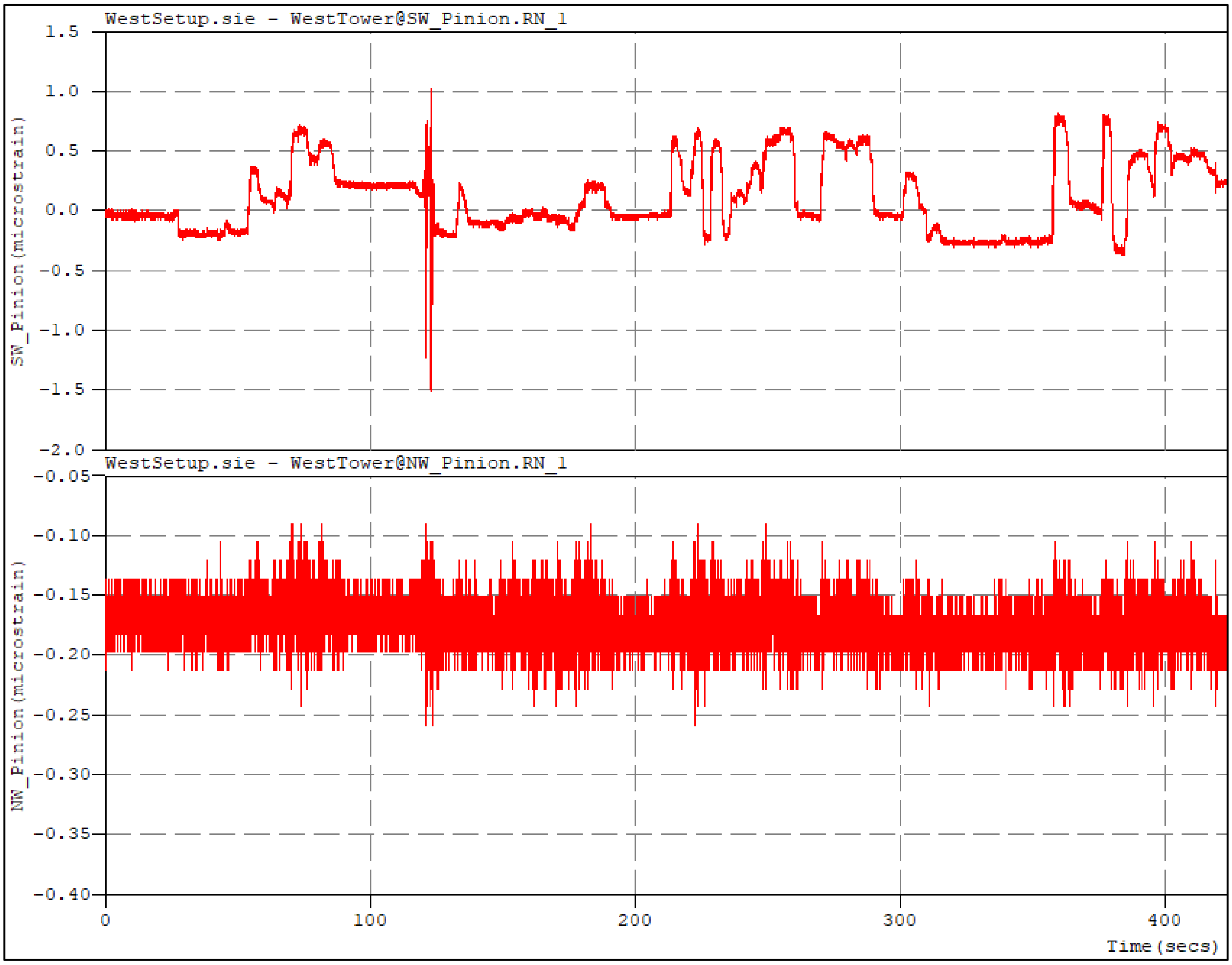


Table 6: Strain gage data under live load traffic

Live Load Shoe Elevation Survey

The approach span and lift span roadway elevations were surveyed near the deck joint at various lift heights. The intent of the survey was to monitor the behavior of the lift span as it seats as well as identify any dimensional concerns.

Elevation measurements were taken at several locations including top of the approach roadway at the movable bridge finger joints, top of the movable span roadway at the tower span deck join at several lift heights, and top of the live load shoe masonry plate. The following table summarizes the balance condition as measured during the time of testing:

Live Load Shoe Elevation Survey	West		East	
	NW	SW*	NE	SE
Survey Measurement Results	(ft)	(ft)	(ft)	(ft)
Approach EL	44.80	44.86	44.79	44.79
Span EL	44.80	44.82	44.79	44.80
Masonry PL EL	32.52	32.59	32.76	32.76
Top of Pier EL	32.27	32.32	32.34	32.34
Cl Truss EL	38.04	38.14	38.23	38.23
Masonry PL to Cl Truss	5.52	5.55	5.47	5.47
Measured Span EL While Open	NW	SW*	NE	SE
8 ft Open	51.67	51.73	51.68	51.75
5 ft Open	48.87	48.92	48.82	48.89
1 ft Open	46.08	46.13	46.02	46.09

Table 7: Live load shoe elevation survey results

Based on the survey observations, it was determined that the bridge is lifting with the south side skewed higher than the north side. This can be affected by the bridge balance or the indexing of the machinery.

Additionally, it was observed that the northwest bridge seat is notably taller than the other bridge seat heights (the bridge seat is the distance between top of roadway to top of pier as surveyed). The position where the current Southwest corner stops appears to be correct per the design bridge seat height. This means the Southwest LLS Strike PL needs to come up to fill that gap.

Span Buffers

The span air buffers were monitored during test operations to determine if there was any holding pressure which could affect the bridge seating. Preliminary calculations show that approximately 40 psi pressure in the buffer correlates to 10 kips loading. Ideally all buffers would relieve any pressure held from span seating to relieve that loading. If there is an issue with the pressure valves and pressure is being held, then that buffer could create an upward load interrupting seating of that corner.

None of the span buffers except for the NW corner were measuring any pressure during seating. NW corner developed up to 200 psi seating pressure but released the pressure normally. NJDOT's maintenance contractor IEW noted they have already explored this as an issue for seating, having adjusted the valves in the past. It did not appear to correct the issue.

INVESTIGATION CONCLUSIONS

Based on the review of the collected data, the west end of the lift span truss appeared to be warped. This is evident by the taller seating height on the Northwest corner compared to the other corners. When accounting for the clearance at the southwest corner live load shoe, the northwest corner is measured approximately 1" taller than the other three corners. It is not clear if the difference in height is an original as-built condition or is a result of a more recent rehabilitation.

A warp also explains how the southwest corner seat is moving when there is live load on the opposite northeast corner, even when that northeast corner is fully seated. Initially this was thought to be due to the bridge teetering on the northwest and southeast corners. This would result in the movable span seesawing under live load, tipping the northeast and southwest corners up and down depending on the direction of traffic. That theory was discounted when the northeast corner was observed to be in fully contact with no movement. The only movement observed was at the southwest corner. A warp in the truss could cause stress in the truss members to pull up the southwest corner from live load on the northeast corner even when that northeast corner is fully seated.

It was not recommended to shim the northeast corner live load shoe and only the southeast corner. Originally, it was believed that shimming the northeast corner would help push the opposite southwest corner down; however, further analysis indicates shimming this corner would make seating issues worse. This corner is the first to seat per the survey data and field observations, meaning increasing the height would also increase the disparity between seating timing. Additionally, the northeast lift span is slightly higher than the approach span. Raising the lift span even higher would impact the roadway rideability. Finally, the seat heights and elevations of the northeast and southeast corners were very consistent.

The balance measurements and comparison indicate that the southwest corner is heavier than then northwest. This should help out the bridge seating and keeping the southwest corner down; however, the imbalance adjustment made in 2021 and the heavier corner load does not appear to reflect the seating issues seen at this corner.

The balance results also suggest that the southwest corner is heavier than the northwest corner and that the slippage is a result of that transverse imbalance; however, this does not reflect what is actually happening. The ropes slip from run to run because the southwest corner is trying to seat higher and higher. If it was an issue of the span imbalance, the southwest corner would try to seat lower and lower. The change in indexing results in the southwest corner of the span drive machinery seeing the higher machinery torque. Additionally, the survey data suggests that the lift span is listing to the north end during operation. A transverse imbalance adjustment to the south could help with seating timing and effect the live load shoe seating.

Currently, work is ongoing to complete the above recommended adjustments.

CREDITS:
Bridge Owner: NJDOT
Preliminary Balance Testing: Gresham Consulting
Contractor: Agate Construction Co.
Contractor’s Engineer: WJE Engineering