HEAVY MOVABLE STRUCTURES, INC.
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Over Height Vehicle Collision Repairs to a Rolling Lift Bridge

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Introduction

On December 28, 2021, DelDOT's bridge 2-021A was impacted by an over height vehicle travelling across the structure. The structure, originally constructed in 1929, consists of steel girder approach spans on either side of the 55' – 10 ½" overhead counterweight rolling lift main span and carries Rehoboth Blvd over the Mispillion River in Milford, DE. The waterway primarily serves pleasure watercraft, and the bridge typically opens for boats a few dozen times per year. Vertical clearance for navigation in the closed position allows smaller watercraft to pass without operation of the movable span which significantly reduces the number of required openings for the structure.

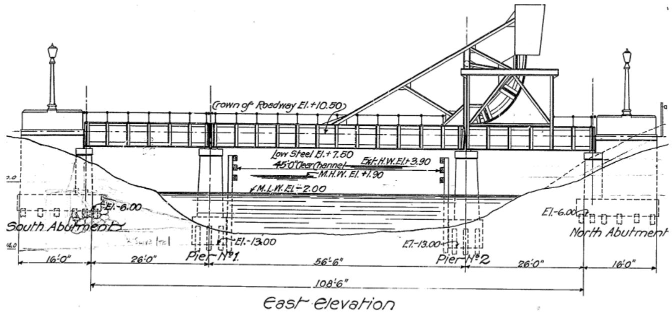

Figure 1: East elevation of existing bridge

The structure was impacted by an excavator on a trailer travelling north on Rehoboth Blvd. The pivot point between the boom and arm of the excavator directly impacted the lower chord of the portal frame which provides stability to the posts and supports the machinery platform. The impact brought the travelling vehicle to a stop and caused significant damage to both the bridge and the excavator as shown in Figures 2 and 3.

Figure 2: Damage to portal frame from impact


Figure 3: Damage to excavator from impact

Inspection and Design

Key Inspection Findings

DelDOT tasked AECOM with the inspection and repair design for the damaged structure. A hands-on structural and mechanical inspection was performed on the structure to determine the extent of damage to the bridge. The inspection identified a number of damaged components to be repaired but there were two overall key findings from the inspection:

1. The movable leaf did not move due to the impact. The lugs on the track girder were still firmly seated within the segmental girder pockets and the leaf was still in the closed position (the direction and location of impact could have caused the leaf to roll open).
2. The damage to the structure was localized to the impact area and surrounding components. There was no global damage that would prevent the structure from continuing to carry vehicular load while repair plans were prepared and implemented.

Structural Findings

Figure 4: Damage to the machinery platform from below

The portal frame lower chord channel where the excavator impacted was significantly deformed as shown in Figure 4. The channel deflected to the point that it came in contact with the rear channel member with the lacing connecting the two channels mangled. The remainder of the portal frame elements including the lower chord gusset plates, diagonal angle members, upper chord gusset plates and upper chord channel members also experienced damage which decreased in relation to the distance from the impact location. The lower chord gusset plates were deformed along with the front channel element. The diagonal angle elements immediately adjacent to the impact were deformed with the front angle at the east post severed completely (see Figure 5). The components at the top chord were deformed slightly but did not present any structural concerns (see Figure 6).

Figure 5: Damage to diagonals

Figure 6: Deformation of upper chord and gussets

When the lower chord front channel member deflected, the east end was pulled toward the center of the bridge by several inches which caused the east stringer to deflect, tearing the web at the bottom of the connection (see Figure 7). Additional damage was sustained to the stringer immediately behind the impact area with the web buckled and the connection damaged including a sheared bolt (see Figure 8).

Figure 7: Damage to east stringer

Figure 8: Damage to stringer in line with impact

Mechanical Findings

In addition to the structural damage sustained by the impact, there were also mechanical components that were affected by the impact. When the ends of the lower chord front channel pulled in, the final drive shafts, S1, were pulled towards the center of the bridge as well via the web bearing connected to the outboard stringers. The shaft on the east side translated inward and rotated in plan while the shaft on the west side appeared to have only translated inward. Gear G2 on the inside of the post was pulled into contact with the steel guard plate (see Figure 9) and evidence of the displacement was apparent at the pinion gear G1 where it was shifted in significantly from the normal position indicated by wear on the gear (see Figure 10).

Figure 9: G2 in contact with guard plate

Figure 10: Pinion pulled towards middle of bridge

Additional Findings

During the inspection process there were condition issues noted with bridge elements which were not related to the bridge impact that occurred on December 28, 2021. Overall there were three primary issues noted including:

1. Damage to portal frame lower chord and counterweight girder from other impacts to the structure that occurred during the life of the structure. These impacts are most evident at the counterweight girder which sits a few inches lower than the portal frame and therefore has a higher potential for impact. As Figure 11 shows, there have been numerous lesser impacts to the structure since the bridge was last rehabilitated in 1996 when the counterweight girder was replaced. The lower flange exhibited significant deformation and in some locations the outstand leg was torn.

Figure 11: Counterweight girder bottom flange

2. The inspection of the bridge was completed using a single lane closure of the roadway with two-way traffic maintained in both directions via flaggers. During the inspection it was noted that the bascule leaf was bouncing at the tip when vehicles crossed the structure. In addition to the bouncing, damage to the lower flange of the bascule girder on the east side was found which indicated that the bouncing was likely an ongoing problem caused by the leaf not being properly seated in the closed position. There were two potential causes identified for this including: the lock bar for the bridge having been modified and no longer maintaining the bridge in the fully closed position and the balance of the structure was modified at some point during the structures history with weight removed from the ends of the bascule girder but no records were available to confirm the existing balance. The lock bar had been modified by cutting the bar to provide additional clearance (approx. ¾”) which was likely done in the past when the pin was unable to be driven.
3. There was significant wear noted on the rack at the fully closed position as shown in Figure 12. This wear was likely related to the bouncing noted but this condition is also not uncommon in bridges of this age. The wear was primarily exhibited on the rack and concentrated on two teeth as the figure shows.

Figure 12: Wear on rack at closed position

Repair Design

The repair scope for the bridge was established using the findings from the hands-on inspection. Structural components were grouped based upon their level of damage and identified for replacement, heat straightening or to be left as-is. Figure 13 summarizes the components of the portal frame and how they were grouped for repair designation. All elements to be replaced were detailed for replacement in kind with rivets replaced with high strength bolts and detailed using the available original construction and rehabilitation design drawings and shop drawings.

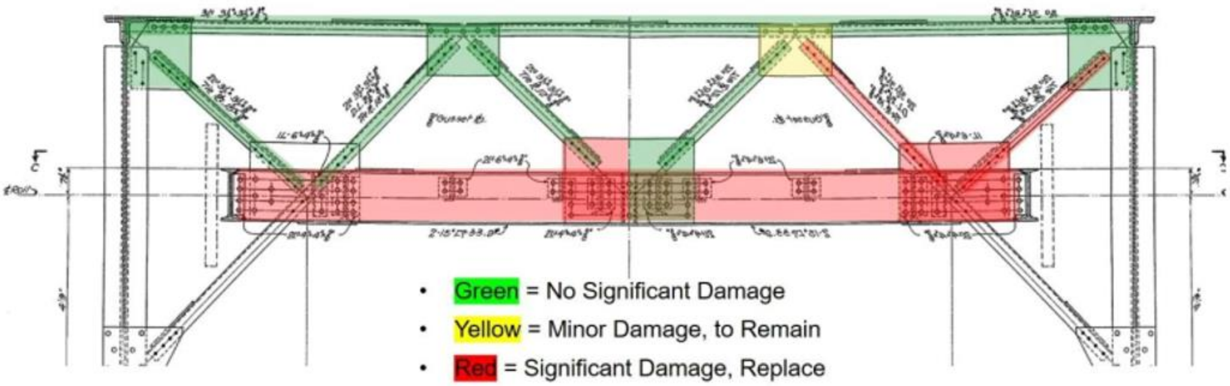

Figure 13: Identification of damage to portal frame elements and actions required

In addition to the repairs to the portal frame, partial replacement of the east stringer was detailed. Consideration was given to full replacement of the stringer but given that 2 mechanical bearings were mounted on the top flange of the stringer in addition to the web bearing which was shifted, it was determined that both schedule and cost savings would be realized by performing a partial replacement. The connection was detailed with a combination of field bolting and welding to develop the necessary capacity within the member.

In addition to the repairs for the damage sustained by the excavator impact, DelDOT also agreed to replace the damaged counterweight girder web and bottom flange. Since the machinery platform would already need to be temporarily supported and the roadway closed for repairs, this presented a good opportunity to perform this work. These elements in addition to the clip angles connecting to the stringers were detailed for replacement in kind similar to the portal frame elements.

As discussed in the findings section, displacement of the mechanical final drive shafts was noted during inspection but no physical damage was visually observed. To ensure that no bending of the shafts or cracking of either the shaft S1 or gears G1 or G2 had occurred, removal and shop testing of these components was detailed within the contract documents. Contingent items were included for shaft S1 and gear G2 replacement if either component were found to have defects from the shop evaluation and testing. Replacement of the bronze bearing liners for web bearings B1 and B2 were included in the contract given that these components had already been in service for over 90 years and with shaft S1 removed replacement of the liners had no significant cost implications.

The mechanical issues unrelated to the excavator impact were also included within the repair contract to be resolved while the bridge was closed for repairs. This included relocation of the rack sections from the fully closed position which were exhibiting wear to the rear of the rack where the rack section was outside of the normal operating range and showed no visible signs of wear. Review of the shop drawings confirmed that the rack segments were machined to the same dimensions and the sections could be exchanged with the holes reamed and new turned bolts installed to secure them.

The noted bouncing of the leaf was addressed by two means. First, strain gage testing of the leaf was prescribed following completion of the repairs to the damaged mechanical and structural components. This testing and subsequent balancing would ensure that the leaf provided a positive reaction at the toe to prevent any tendency for the toe to lift and allow bouncing. Second, the lock bar which had been modified was detailed to be rotated such that the unmodified top of the bar would be the contact surface and the bar was to be re-shimmed for a tight fit. See Figure 14 for photo of modification of and prescribed repair detail.

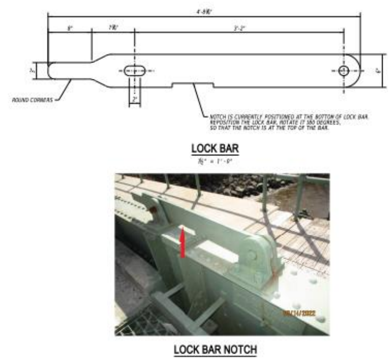

Figure 14: Repair detail for lock bar

Construction

Issues Encountered

DelDOT awarded the repair contract to Covington Machine & Welding under an open-end contract to expedite the repairs to the structure. Covington mobilized their team and performed collection of field data including field measurements and verification of the alignment of mechanical components. Based upon their evaluation of the prescribed repairs, the contractor proposed full replacement of the east stringer rather than the partial replacement that was prescribed in the contract documents. Due to the amount of work to remove the attached components and reinstall them including 2 additional bearing housings with associated shafts and the deck plate for the machinery platform, discussions were held regarding the approach that was best for the project schedule and budget. The contractor confirmed that changing to a full replacement would not lengthen the detour duration for construction or add any construction cost so the change was accepted.

The contractor was preparing to mobilize for the closure of the roadway to begin repairs when on December 30, 2022, a year and 2 days after the original impact, the bridge was again struck by an excavator being trailered on the bridge. The vehicle was travelling in the same direction and impacted nearly the same location but this impact had one key difference: the excavator impacted the portal frame lower chord but then continued beyond the distorted member and impacted the counterweight girder which had a slightly lesser vertical clearance and brought the vehicle

Figure 15: Damage to counterweight girder

to a stop. The damage from this second impact was assessed via another hands-on inspection. The additional damage to the portal frame did not affect any elements not already planned for replacement but the impact to the counterweight girder was significant as Figure 15 shows where the web was distorted several inches and connection plates badly damaged. Thankfully, these elements were already prescribed for replacement to address the other impacts to the structure and shop drawings had already been prepared and approved.

The most significant additional damage to the structure was the fact that the impact had actually shifted the machinery platform on the east side which caused misalignment of the mechanical drivetrain, shaft S3 on the east side was found to be bent and the east post showed signs of a slight twist. The misalignment of the mechanical equipment now required the entire drivetrain to be reset and new turned bolt to be installed for all bearing housings. This added both cost and time to the repair contract which led to an extended roadway detour duration. Shaft S3 was removed from the structure for shop evaluation and S2 was also removed to confirm it had not been bent as well. The east post was evaluated but the amount of twist did not cause structural concerns. The main concern was that the twisted post housed the web bearing B1 and the alignment of the bearing was now in the incorrect orientation.

The final challenge presented during construction was that the gib keys for gear G1 on the west side had been cut off and a cap placed over the end of the shaft (see Figure 16). Removing the keys from the shaft on the east side of the bridge presented challenges for the contractor as one of the keys was missing the gib head. By fabricating a jig and welding onto the end of the key the contractor was able to extract both keys. With no exposed keys on the west side of the bridge it seemed very likely that removing the gear would prove nearly impossible without irreparably damaging the gear and/or shaft. Having removed shaft S1 on the east side of the bridge, confirming straightness and performing testing to confirm that no cracks were present within the shaft or gears it was clear that the shaft on the west side of the bridge which was minimally displaced was very unlikely to have any issues. With this in mind, the contractor was allowed to field verify straightness of the shaft to confirm there was no damage and leave the shaft in place.

Figure 16: Missing gib head, east (top); cut off keys with cap, west (bottom)

Unique Repair Methods Used

To expedite the construction process and avoid the need for more extensive, costly and time-consuming repairs, unique construction methods were utilized. These methods were primarily related to the mechanical equipment realignment. When east shaft S3 was taken to the shop the out of straightness was measured and determined to be on the order of 3/8”, well outside of the allowable runout tolerances. With the long lead time required to procure shaft material and machine a new shaft in addition to the risks of damaging the gear when removing it from the shaft, the contractor recommended straightening of the existing shaft. Using a setup on V blocks as shown in Figure 17 and a hydraulic press the contractor was able to straighten the shaft and confirm that the runout was within the acceptable tolerances for a new shaft which saved significant time and costs for the project.

Figure 17: V block setup used in contractors' shop

The other key challenge presented for the mechanical equipment was in the misalignment of the post on the east side of the bridge. To ensure that no binding or accelerated wear would occur on the reinstalled bearing housing, the alignment needed to be adjusted from the alignment with the housing bolted directly to the post web. The conventional option would be to bring in an in-place machining operation to machine the web of the post to provide a bearing surface in the proper orientation for the web bearing. This type of work is very costly and takes a significant amount of time to perform as few companies perform this type of work. With the roadway under a full detour, designers looked for alternative ways to realign the bearing and recommended use of an epoxy bedding compound to provide a sound bearing between the housing and post web. The contractor reinstalled and aligned the bearing within the post web with shims between the two elements and undersized high strength bolts holding the housing in place. They then dammed around the housing and poured the bedding compound into the gap between the two elements. Once cured, the bolts were removed and turned bolts were installed to connect the elements.

DelDOT Plans for Preventing Future Impacts

Figure 18: "Clankers" installed in Newark, DE

In addition to the two significant impacts leading to the need for emergency repairs to the bridge, damage was viewed during the inspection which was not attributed to either of the noted impacts. This evidence that impacts to the bridge have been somewhat common throughout the bridge's life indicate that continued damage could be expected if no further measures are taken. DelDOT was able to recently implement a successful over height warning system on another roadway within the state, the Casho Mill Road underpass located in Newark, DE (see Figure 18). This system, referred to as "clankers", was installed in the summer of 2022 and is comprised of hanging spheres which when impacted cause a non-damaging warning to motorists. The system has prevented multiple incidents as evidenced by DelDOT's traffic camera at the location. DelDOT intends to install a similar system at BR 2-021A and is currently in the design phase.