ABSTRACT

PennDOT recently completed the replacement of the SR 345 Highway Bridge over the Schuylkill River and Norfolk Southern’s (NS) Harrisburg Mainline in Birdsdoro, Pennsylvania.

The existing 9 span viaduct consisted of heavily deteriorated concrete arches, including the 108’ end span over NS’ three tracks. Removal by blasting was originally investigated by the contractor, but was rejected by the project sponsor (PennDOT). The second proposed alternative consisted of a controlled segmental removal utilizing four support towers. Due to the poor condition of the arch, predicted behavior during segmental removal of the bridge would be difficult and unsafe and the significantly long track outages, upwards of two weeks on Mainline No. 2, were not feasible to maintain NS’ operations.

The approved removal plan consisted of a controlled progressive collapse of the entire bridge occurring in three stages, with the third and final stage consisting of the span over NS. The track was protected by softening mounds and steel plated timber mats at grade which also served as work platforms for the contractor during the concrete removal process. The entire span was dropped to grade and removed in under 8 hours with no impacts to NS rail operations.

This paper will present how outside party projects can routinely impact railroad operations, detail the project constraints and the process implemented to determine a solution, and demonstrate how effective communication and an understanding of both the railroad’s requirements and the project sponsor’s constraints led to the safe removal of the bridge.
OVERVIEW OF PUBLIC PROJECTS

The Norfolk Southern Railway’s (NS) Public Projects team is involved in a wide variety of projects originated by government agencies, local businesses and private developers. Each year approximately 200 new public projects are initiated by these outside parties requiring NS to focus their efforts on supporting projects that do not promote their core business of moving trains. If not thoroughly reviewed, impacts from these projects can cause delays to NS train operations, unwanted changes to NS right of way and facilities, and ultimately endanger the safety of NS personnel and the general public. The varieties of these projects are detailed in the following list:

- **Highway-Rail Grade Crossings**: Closure, removal, installation and alterations of public and private highway-rail grade crossings.
- **Bridges Over NS**: Construction, reconstruction, rehabilitation, repair, removal and maintenance of bridges over the railroad by outside parties.
- **Bridges Carrying NS**: Construction, reconstruction, rehabilitation, repair, removal, and maintenance of bridges carrying NS over highways and other public properties initiated by outside parties.
- **Parallel Roads/Facilities**: Construction, reconstruction, modification, removal, and maintenance of parallel roads or other public facilities affecting NS property or operations.
- **Beautification**: Modification of structures over or adjacent to the railroad involving aesthetic work only.
- **Bridge Painting**: Painting of structures over or adjacent to NS property.
- **Landscaping**: Non-structural modifications to land on, adjacent to, or impacting NS right-of-way (ROW).
- **Other Projects Involving NS Rail Corridors**: Publicly sponsored projects involving or altering NS facilities or its property, including highway construction, drainage improvements or other activities that require access to NS ROW or property.

During the review of these projects, NS places the highest priority on safety – for its employees and for the public, but it must also give careful consideration to anything that could adversely affect customer service, compensation for use of railroad property, and risk to railroad operation. In order to assist in the handling of these projects, NS engages General Engineering Consultants (GEC) to provide administrative and engineering services. AECOM has served as a primary GEC for NS since 2007. In addition to providing engineering reviews and construction monitoring, one of AECOM’s main responsibilities under this contract is to facilitate the accurate and timely communication of information between NS and the outside parties in order to improve planning, develop relationships, and ultimately provide for the successful completion of these projects.

PROJECT BACKGROUND & CONSTRAINTS

In October of 2010, the Pennsylvania Department of Transportation (PennDOT) initiated a public project with NS for the replacement of the SR 345 viaduct over the Schuylkill River and NS in Birdsboro, Pennsylvania. The project involved the replacement of the existing 9-span bridge viaduct with a new multi-bridge viaduct on a new alignment and the complete removal of the existing bridge structure. Norfolk Southern’s Harrisburg Mainline Track No. 1 and Track No. 2 and a secondary track (Turkey Path) were located under the existing span 9 on the northern end of the project limits.
Figure 1 – Existing Bridge and Track Layout – Turkey Path is the leftmost track

Existing Bridge Conditions

The existing nine (9) span viaduct was constructed as a monolithic concrete spandrel arch bridge in 1927. In recent years, the poor condition of the bridge had required that the bridge be posted for a 15 ton weight limit, and ultimately replaced. In 2010, PennDOT listed the Birdsboro Bridge as the worst-rated in the state. At the start of the replacement project the existing bridge structure exhibited heavy concrete deterioration with some of the worse conditions occurring in the 108’ end span over NS’ three tracks. This span exhibited excessive spalling in the arch ribs, overhangs, spandrel columns, floor beams, and deck underside, as well as noticeable corrosion of exposed rebar sections. Preconstruction site conditions showed the area below the span over NS to be littered with concrete debris from spalls on the bridge ranging in diameter from a couple of inches upwards to two feet. Coming into this project, NS already had heightened concerns given the overall condition of the bridge and the potential impacts to their operations through this area.
Railroad Operations

This section of NS’ system carries two (2) mainline tracks and serves as a vital corridor connecting Philadelphia to Reading and Harrisburg, PA. With multiple vertical clearance restrictions on the Harrisburg Main Line through Reading, the Turkey Path track serves as a main route for double stack train movements between Harrisburg and Philadelphia. Trains operate through this corridor under a maximum authorized speed of 50 mph. The typical traffic on this line averages 15 – 20 trains a day with additional movements for local switching operations. The overall tonnage of this line is fourteen million tons with primary loads including intermodal double stacks, crude oil, and priority mail. With typical maximum windows between trains passing through the project site around three (3) hours and the twenty-four (24) hour movements of these trains, understanding NS operations was critical to determining the appropriate removal methods for the bridge. Early coordination with NS’ Transportation Group, through the local NS Bridge Supervisor and Assistant Division Engineer for Bridges and Structures, helped to establish the initial allowable parameters needed to maintain NS’ operations. These parameters included that all three (3) tracks were to remain in service at all times and that the maximum track outage that could be provided was eight (8) hours. The eight (8) hour outage was contingent upon the outage occurring simultaneously on all three (3) tracks and that NS was provided with a minimum of three (3) months to schedule this outage.

Removal Alternatives

On February 16, 2014, PennDOT’s contractor, JD Eckman, Inc., submitted a demolition white paper to NS outlining three proposed removal options for the existing bridge structure. The options included conventional demolition methods, controlled blasting, and a controlled collapse. Each option was initially reviewed by AECOM for impacts to NS’ operations and potential physical impacts to NS right of way.
Conventional Demolition

The proposed Conventional Demolition operation would have required a minimum of four (4) temporary shoring towers to support the main arch ribs during a segmental removal of the deck, floor beams, and ribs. The proposed shoring tower locations would have required taking the NS maintenance road and potentially one mainline track out of service for a period of two weeks. This time would have been required to erect the temporary shoring towers, install debris shielding, remove the bridge, and remove the shoring towers. Deck removal during this operation would have required the use of demolition debris shields. Due to the condition of the bridge, predicted behavior during segmental removal of the bridge would be difficult and possibly create unsafe working conditions. Ultimately due to the type and length of impacts to NS’ operations, this option was not deemed as a feasible option for this project.

Controlled Blasting

The proposed Controlled Blasting Operation consisted of wrapping the main arches in chain link fence and placing blasting charges in pre-drilled holes throughout the length of the arch. The main arch would then be blasted into smaller sections, confined within the chain link fence, freeing the arch from its supports and ultimately leading to the collapse of the entire bridge span to grade. Installation of the fencing, predrilling of the holes, and placement of the blasting charges were proposed to occur in advance of any track outages under normal railroad flagging protection. The contractor anticipated needing an eight (8) hour track window to install track protection, blast the structure, and remove the debris. Initial concerns for this method included running trains under the bridge with blasting charges installed, the effectiveness of the fencing to contain the debris, the type of physical track protection required, and the feasibility of completing this work in the proposed eight (8) hour window.

Controlled Progressive Collapse

The final proposed method consisted of a progressive collapse of the bridge viaduct in three phases. Phase I included spans 1 & 2, Phase II included spans 3 through 7, and the third and final phase included spans 8 and 9. Spans to be removed in each phase would be precut at the base of each end of each arch. The depth of each cut would be such that all longitudinal reinforcing in the arches was severed from the supports, ultimately eliminating any tension capacity in the arch ribs. The contractor then proposed utilizing hydraulic breaking rams to simultaneously break through each concrete arch rib at one end causing that end to fall. Freeing the end of the arch from its support would remove the compression force in the arch and put the opposite end of the arch into tension. With the tension support already being precut, the span would then fall to the ground under its own self weight. Once the first span dropped, this would eliminate the counterforce at the shared support for the next span, placing the precut arch in the adjacent span into tension. The spans would then progressively collapse under their own self weight in a domino effect. Temporary arch supports and roadway plate ties across the expansion joints would be utilized to control the number of spans that collapsed in each phase.
The contractor anticipated needing a fourteen (14) hour outage to complete the installation of track protection, dropping of the span, and removal of all debris. Initial concerns for this method included the uncertainty of utilizing an atypical demolition method, the type of physical track protection required, and the feasibility of completing this work in the required eight (8) hour window, not the requested fourteen (14) hour window.

**SELECTION OF DEMOLITION METHOD**

On April 9th, 2014, representatives from NS, AECOM, PennDOT, and JD Eckman met onsite to discuss NS’ concerns with the two viable removal methods and to determine the method that would best accommodate NS’ operations. After reviewing the white paper submitted by JD Eckman, NS’ preferred option for removal was the controlled blasting scheme; however, due to the Pennsylvania Department of Environmental Protection’s restrictions at the project site, and contractual limitations on blasting placed in PennDOT’s original construction bid package, PennDOT would not allow their contractor to utilize the controlled blasting method.

This left the controlled progressive collapse as the preferred alternative for removal, but NS still had major concerns regarding the track time needed for the removal, protection of the track structure, and that the contractor, PennDOT, and NS had limited to no experience with this removal method. Because of the phased demolition sequence, NS decided that approval for the Phase III demolition over NS tracks, would not be issued until the successful completion of Phases I & II. The goal was to take what was learned in Phases I & II and apply that information to the removal of Phase III to help increase the efficiency of the span removal over the tracks.

**Demolition Submittal No. 1**

The initial Demolition Submittal came in three submissions over a time period ranging from 5/6/14 to 7/7/14. These initial submittals encompassed all three phases and detailed the overall removal plan for the bridge, including finite element analysis models, design calculations, and the initial means and
methods for the removal over NS. AECOM’s review of the finite element analysis and design calculations from an engineering perspective confirmed that the constructor’s plan for a progressive collapse of the entire bridge in stages prevented by arch supports and tie plates across expansion joints was a feasible removal method.

The contractor’s initial means and methods for Phase III included track protection that consisted of spanning the tracks, upwards to 12-feet, with 12-inch thick timbers and flooding the entire area under bridge and 30-feet on each side with 24-inches of ballast. Their estimated time to install the track protection and remove the bridge was 14 hours. The timeline provided required 6 hours just for the set-up and removal of the track protection and provided limited details for the remainder of the removal operations.

![Figure 4A – Initial Track Protection Plan](image-url)
AECOM’s review of this submittal highlighted that for the given span length and expected load, the timbers provided for the track protection were prone to failure and could possibly damage the track structure. Not only was the requested 14 hour outage not feasible, it was noted that the time required for the installation and removal of the track protection was not an efficient use of the requested track window. Furthermore, the plan lacked details for the progression of the removal operations and the equipment needed once the structure was on the ground.

With a goal of trying to develop a clearly defined timeline for each activity during the track outage, AECOM worked with the contractor to revise the proposed track protection plan. AECOM’s recommendations included the installation of longitudinal at-grade timber crossing panels, shimmed such that the top of the timber sat above the top of the rail by a minimum of 1 inch. These panels would serve as the base of the proposed track protection and would allow for the placement of transverse timbers over the rails. This reduced the span of the transverse timbers over the rails from 12'-0" to 1'-0". Finally softening mounds were recommended to be placed at the proposed impact locations on the outside of each exterior track. The proposed track protection method would eliminate the need for the placement and removal of the stone protection layer. It also allowed for the installation and the removal of the first layer of timbers and the softening mounds to occur outside of the requested outage under normal flagging protection.

Demolition Submittal No. 2

The revised demolition procedure for Phase III was submitted on August 1, 2014. This submittal incorporated the recommended track protection measures, and included provisions for 3'-0" x 3'-0" softening mounds. The equipment staging for the removal procedure was also further defined. In this submittal the contractor was proposing to use four (4) excavators. Two (2) excavators with hydraulic rams would be located behind the abutment for the initial hammering of the arch ribs. The other two (2) excavators with buckets would be located on the ground and would be responsible for loading sections of the bridge onto waiting rock trucks. The two (2) excavators located behind the abutment would transverse the project site to get to ground level after the span had fallen, in order to assist in the breakdown of the bridge structure on the ground. The updated timeline for the required outage was now ten (10) hours.
Figure 5A – Revised Track Protection Plan

Figure 5B – Revised Track Protection Section

5 ft x 12 ft Crane Mats laid transversely over existing tracks per typical track protection section this sheet.

Stone softening mound full length of track protection. Final dimensions to be coordinated with Norfolk/Southern Railroad recommendations.

5 ft x 12 ft x 1 ft Tall Timber—crane mats laid transversely over each track and centered on centerline of track gage. See plan for extents.

Stone softening mound installed on outside of exterior tracks as shown. Final dimensions to be coordinated with Norfolk/Southern Railroad recommendations.

Continuous longitudinal timber cribbing full length of timber mats above. Top of cribbing to be 2" minimum clear above head of existing rail.

Typically, within extents of track protection area, existing ballast to be filled level with top of existing ties for timber mat seating.

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In an effort to further reduce the outage time required, AECOM coordinated with the contractor during the August 5, 2014 PennDOT pre-demolition meeting to identify steps in the demolition procedure that could be refined to expedite the removal of the bridge once it was on the ground. AECOM requested that the contractor consider removing the bridge barrier prior to the outage to reduce the concrete on the ground. AECOM also recommended filling in the gaps between the second layer of timbers on the track protection to create a large work platform that would allow for additional equipment to aid in the breakdown and removal of the concrete. At this time it was decided to withhold a formal response of this submittal until after the Phase I and Phase II demolitions were complete.

**Phase I and Phase II Demolitions**

Phase I and Phase II Demolitions occurred on September 3, 2014 and September 24, 2014, respectively. During both of these operations, AECOM had personnel onsite to monitor and record the behavior of the bridge during the controlled collapse. Review of videos and onsite reports revealed the following:

- The analysis was correct. The spans collapsed as predicted, almost completely vertical and in-plane, and the progressive collapse stopped as anticipated at the arch supports.
- From the start of hammering of arches to when the span was finally on the ground took approximately 45 minutes for each phase.
- There was no reinforcement visible between the barrier and deck. In both phases, the barrier cleanly separated from the deck at the time of impact; therefore, there would be no discernable benefit to removing the barrier prior to outage.
- Bridge was stable after reinforcement sawcuts in the arch.
- Bridge was stable after removal of deck and spandrel columns over pier.
- Evidence of a heavy amount of reinforcement in the deck. Large sections of the deck remained intact after the impact. To create more manageable sections, transverse sawcuts on the deck should be investigated to expedite the removal.

![Figure 6 – Phase II Demolition – Span 6 Post Collapse Condition](image)
On October 7, 2014, all parties conducted an onsite railroad specific pre-demolition meeting to discuss the outstanding Demolition Submission No. 2 and the findings from the Phase I and Phase II Demolition. At this meeting, the contractor was encouraged to provide the following in the resubmission:

- Provide the additional transverse sawcuts in the deck. This work to occur prior to the outage.
- Provide the extended work platform/track protection to allow for the placement of more equipment on the ground. At a minimum, the contractor should provide six (6) excavators with hydraulic rams and buckets, and two (2) dozers capable of pushing debris across the work platforms and clear of the track.
- Increase the softening mounds size to reduce the impact at the track level.
- Detail all equipment locations and movements to reduce the track outage window required.

Demolition Submittal No. 3

On October 10, 2014, JD Eckman provided their final demolition plan for the Phase III Demolition. This plan incorporated all of the recommendations provided by AECOM and NS at the October 7, 2014 onsite meeting.

Figure 7 – Final Track Protection and Equipment Plan
As part of this plan the contractor had revised the equipment locations and could now utilize two (2) excavators on the ground level and two (2) excavators at the abutment to break the arch free at all four (4) corners. The excavators were equipped with quick disconnect fittings to allow for the hydraulic rams on the excavators to be quickly changed out to buckets as needed. The final requested track outage was now reduced to eight (8) hours, with a majority of the track protection and bridge preparation work occurring outside of the outage during normal flagging protection.

Final approval of the demolition plan was issued on November 3, 2014. At this time, outages to complete this work were scheduled for November 16, 2014. The Turkey Path Track would be taken out of service from 4:00 AM to 3:00 PM and the Mainline Tracks from 7:00 AM to 3:00 PM. The contractor was requested to clear the tracks progressing from Mainline Track 1 to Turkey Path Track. Due to union labor rules, NS would be required to install the first layer of timbers for the track protection. Finally, arrangements were made with NS Assistant Division Engineer of Track to have track forces on hand during the demolition to inspect the track structure after the bridge removal and to make any necessary adjustments or repairs.

**Phase III Demolition**

In the week proceeding November 16, 2014, all of the advanced work was completed under normal flagging protection with no impacts to NS operations. Work included

- Installation of longitudinal timbers by NS forces
- Installation of additional ballast for the work platform build out
- Installation of the softening mounds
- Transverse deck sawcuts and removal of deck and spandrel columns over the pier and abutment
- Arch reinforcement sawcuts (48 hours prior to outage)

At 4:01AM on November 16, 2014, track outages were initiated and the Phase III Demolition work was under way. The following represents the timeline of events during the demolition:
4:01 AM  Turkey Path track outage begins.
6:01 AM/5:58 AM  Mainline track 1 and 2 outage begins.
6:30 AM  Track protection complete. Hammering begins.
7:15 AM  Bridge collapses.
12:10 PM  Mainline track 2 uncovered/inspected.
12:20 PM  Turkey Path track uncovered/inspected. Two low points noted.
12:50 PM  Mainline track 1 uncover/inspected.
1:20 PM/1:31 PM  Mainline track 1 and 2 given back.
1:25 PM  Repairs to Turkey Path track begin (low points tamped up)
2:14 PM  Turkey Path track given back.

Figure 9 – Installation of Track Level Protection
Figure 10 – Hammering of Main Arch Ribs

Figure 11 – Condition Immediately Following Controlled Collapse
Figure 12 – Bridge Removal Operation

Figure 13 – Track Protection Removal and Track Inspections
SUMMARY AND CONCLUSIONS
Throughout this process, AECOM utilized their understanding of both NS’ operations and PennDOT’s constraints to facilitate the accurate and timely communication of information between NS, PennDOT and JD Eckman. This approach engaged all stake holders to forge relationships that developed the best practices in a cooperative atmosphere and focus on continual improvement of the demolition plan for the benefit of all parties. After 10-months of planning and continued communication, the well-orchestrated demolition plan proceeded as predicted and the bridge was successfully removed within the provided track outage and with no impacts to NS operations or property.

ACKNOWLEDGEMENTS
Gerry Johnston – Norfolk Southern – ADE Bridges, Harrisburg Division (Retired)
Mark Serfass – Norfolk Southern – Bridge and Building Supervisor
Norfolk Southern Transportation Group
Josh Amsler, PE – AECOM – Construction Monitoring Representative
PennDOT District 5-0
JD Eckman, Inc.

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Controlled Progressive Collapse of PA SR345 Concrete Arch Bridge over Norfolk Southern’s Harrisburg Mainline

Thomas Bracey—Norfolk Southern
Matthew Walicki—PE-AECOM
Over 2000 Active Public Projects Including:
- Highway-Rail Grade Crossings
- Bridges Over NS
- Bridges Carrying NS
- Parallel Roads/Facilities
- Beautification
- Bridge Painting
- Landscaping
- Drainage Improvements

PROJECT SITE
(BIRDSBORO, PA)
### Demolition Plan Progression

- Demolition Methods White Paper: 2/6/14
  - NSR/AECOM/JDE Meeting: 4/9/14
- Submission 1: 5/6/14
- Submission 1.1: 5/30/14 & 7/7/14
- Submission 2: 8/1/14
  - PennDOT Pre-Demo Meeting: 8/5/14
  - Phase 1 Demo: 9/3/14
  - Phase 2 Demo: 9/24/14 & 9/25/14
  - NSR/JDE Meeting: 10/7/14
- Submission 3: 10/10/14

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Demolition Methods White Paper

- **Conventional Demolition**
  - Shoring Tower placement would require the NS access road and one mainline track to be taken out of service for two weeks.
  - Predicted behavior during segmental removal of the bridge would be difficult and unsafe for train operations.
  - Significantly longer than other alternatives.

- **Controlled Blasting**
  - NS Preferred but ultimately not allowed by PennDOT.

- **Controlled Collapse**
  - Determined to be the safest alternative for NS Train Operations.
  - Able to test the method and determine the timeframe required on a different span prior to over NSR.
Demolition Submission No. 2  
August 1, 2014

Phases 1 & 2 – What We Learned
Demolition Submission No. 3
October 10, 2014

Advance Demolition Work
Demolition Time Line

4:01 AM – Turkey Path track outage begins.
6:01 AM – Mainline track 1 and 2 outage begins.
6:30 AM – Track protection complete. Hammering begins.
7:15 AM – Bridge collapses.
12:10 PM – Mainline track 2 uncovered/inspected.
12:20 PM – Turkey Path track uncovered/inspected.
12:50 PM – Mainline track 1 uncover/inspected.
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