Cost Effective Alternatives for Mitigating Debris and Environmental Impacts Around Bridge Piers

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Prepared for:
The Ohio Department of Transportation,
Office of Statewide Planning & Research

Project ID Number: *109461*

December 2024

Final Report

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/OH-2024/29		

4. Title and Subtitle	5. Report Date
Cost Effective Alternatives for Mitigating Debris and Environmental Impacts Around Bridge Piers	**December 2024**
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
Jonathan D. Witter	
9. Performing Organization Name and Address	10. Work Unit No. (TRAIS)
Ohio State Agricultural Technical Institute 1328 Dover Road Wooster, OH 44691	
	11. Contract or Grant No.
	33807
12. Sponsoring Agency Name and Address	13. Type of Report and Period Covered
Ohio Department of Transportation 1980 West Broad Street Columbus, Ohio 43223	**Final Report**
	14. Sponsoring Agency Code

15. Supplementary Notes

None

16. Abstract

This research study addressed three key problems: 1) identifying safer, timely, and cost-effective solutions for removing accumulated debris from bridge piers, 2) designing and implementing countermeasures to prevent debris accumulation, and 3) finding technological solutions to enhance bridge inspection, scour detection, and mapping of river cross sections. The project evaluated various equipment solutions for debris removal, ultimately developing and testing a custom knuckleboom crane with grapple and saw attachments. The knuckleboom crane improved worker safety, minimized lane closures, and allowed for streamlined environmental permitting. On small projects completed by ODOT County forces, labor was reduced by 43%. Large or difficult projects that have typically been sold to contractors can now be completed by ODOT forces with cost reductions ~80-90%.

Numerous methods and materials were evaluated to develop strategies to mitigate debris accumulations and counteract scour. Chevron vane structures were designed and implemented at SR 122 over the Great Miami River in Butler County to better align river flow and direct debris away from piers. Debris snagging on piers has been greatly reduced, but not fully eliminated. Debris removal in conjunction with the mitigation measures has been highly effective. Additionally, a cross-vane structure was implemented at SR 52 over Ray's Run in Clermont County. The vane was constructed to address scour of the abutments. The project remedied systemic degradation of the streambed and halted scour.

The research also explored remote, non-contact methods to aid in subsurface investigations for bridge inspection primarily focused on sites with water depths >5-feet. Demonstrations of uncrewed surface water vehicles and single and multibeam sonar were coordinated and used to evaluate hardware, sensors, software, and outputs. These technologies provided valuable data for evaluating scour and establishing repeatable cross sections for change detection in subsequent surveys. To facilitate technology transfer, multimedia educational materials were developed.

17. Keywords	18. Distribution Statement
Debris, removal, mitigation, bridge, pier, scour, vane	**No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161**

19. Security Classification (of this report)	20. Security Classification (of this page)	21. No. of Pages	22. Price
Unclassified	**Unclassified**	**24**	

Form DOT F 1700.7 (8-72) **Reproduction of completed pages authorized**

Acknowledgements

The author would like to thank the Ohio Department of Transportation (ODOT) and the Federal Highway Administration (FHWA) for sponsoring this study. The Technical Advisory Committee (TAC) members and numerous District and County ODOT staff including Brandon Collett, Jonathan Wells, Maxwell Bailey, Joe Smithson, Anthony Pankala, Eric Schmidt, Keith Smith, Shane Jones, Shawn Sutton, Scott Hall, Daniel Kammer, Jamie Davis, Helen Corkum and others made meaningful contributions to the effort as well as providing supervisory oversight. Jill Martindale provided excellent project management and internal coordination with ODOT throughout the course of the project. Michelle Lucas and Vicky Fout provided additional research administration support. John Hunt, Peter Haug, and James Hitchman of Ayres Associates worked closely with the lead researchers including Dan Mecklenburg of The Ohio State University to model and design the chevron vane structure for debris mitigation. Christy Pirkle and Christine Rahtz of EMH&T Inc. skillfully handled environmental permitting issues related to implementation of the chevron vane. Kendall Giar, Luke Kelly, and Kim Osborn of Palfinger USA provided creative solutions for design and delivery of the custom counterweighted knuckleboom crane for debris removal. Seafloor Systems, Xylem, Maritime Robotics, and Norbit ASA provided demonstrations and technical support on Uncrewed Surface Vehicles and sonar for hydrographic surveying and scour detection.

Prepared in cooperation with the Ohio Department of Transportation
and the U.S. Department of Transportation, Federal Highway Administration

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1. Problem Statement

Accumulations of debris on bridge piers can obstruct, contract, or redirect river flows leading to 1) rise in water surface elevations for high flow events causing more frequent flooding and greater potential for overtopping the roadway (Lyn et al., 2007; Sheeder and Johnson, 2008), 2) bank erosion and subsequent misalignment of the channel through the opening (Johnson et al., 2010), 3) localized scour of the river bed around piers potentially undermining the bridge foundation (Lagasse et al., 2010), and 4) increased horizontal forces to piers that may directly damage the substructure or indirectly stress components of the superstructure (Bradley et al, 2005). While catastrophic failure of a bridge due to debris is rare, the need for difficult and dangerous maintenance to remedy accumulations is common and can be costly to ameliorate. While small debris accumulations are often removed by Ohio Department of Transportation (ODOT) county staff using chainsaws deployed from small boats, long reach excavators, or lattice boom cranes deployed from the bridge deck (Figure 1 Appendix A), larger and more difficult projects are typically completed by contractors. An analysis of the ODOT project management database from 2005-2024 revealed that contractors charged $25,330-$69,110 (inflation adjusted to October 2024) per site for debris removal (Table 1 Appendix A). Furthermore, these projects typically take ~1-year to complete and cost figures do not include ODOT internal costs to design, contract, and administer the projects. Numerous researchers (Diehl, 1997; Sheeder and Johnson, 2008) suggest that debris removal can be a major component of the overall life cycle costs of a structure and that effective maintenance programs to remove or avoid debris accumulations is an efficient means to preserve and extend bridge service life (Pangallo et al. 1992).

While removal of debris accumulations is the most common countermeasure to protect the bridge, proactive implementation of practices to avoid future maintenance may be a preferable alternative at sites with difficult access and recurrent problems (Diehl, 1997; Lagasse et al., 2010). Alternatives to removal include a suite of non-structural management (e.g. tree cutting and disposal along unstable upstream riverbanks) and structural or hydraulic practices (e.g. debris deflectors, fins, sweepers, natural channel design practices, submerged vanes, etc.) to align flow and guide debris away from piers. Given the difficulty of implementing practices outside of established road right-of-way, structural practices in the vicinity of the bridge opening are more likely to be viable maintenance solutions for ODOT. Unfortunately, little information and guidance is available on the selection, reliability, performance, and cost-effectiveness of these countermeasures (Sheeder and Johnson, 2008). Furthermore, the application of these practices by ODOT workers in a large river environment is not well established.

Monitoring of bridge piers for scour and submerged debris accumulations is an important facet of bridge inspection and maintenance. As structures age, ensuring their safety and structural integrity becomes increasingly important. Currently, National Bridge Inspection Standards (NBIS; 23 CFR Part 650 Subpart C) and Ohio Revised Code (ORC §5501.47) outline standard inspection frequencies and criteria for extending or reducing inspection intervals. Typically, underwater inspections are conducted at 60-month intervals but may be reduced to 24-months depending on site conditions and potential risks. In Ohio, routine bridge inspections are based on a Reliability Based Inspection (RBI) interval, not to exceed 24-months, and may be reduced to annual inspections for bridges that meet multiple criteria (e.g., structure type, size, condition rating, design complexity, etc.). During routine inspections, information on substructure condition and stability is typically gathered by inspectors during low flow periods through visual observations or probing to detect scour. Moreover, Addendum 1 (ODOT, 2017) of the ODOT Manual of Bridge Inspection (2014) requires regular measurement of channel cross section elevations to detect change due to channel scour, degradation, and/or lateral streambank migration in subsequent surveys. For channels with water depths >5-feet, inspection of subsurface components and measurement of channel cross sections may be difficult, unsafe, time-consuming, and limited in their ability to detect significant defects.

2. Research Background

2.1 Debris Removal and Mitigation

The overall goal of this phase of the study is to identify and evaluate a suite of equipment options and best management practices for removal of debris accumulations from bridge piers and to design, implement, and monitor structures to prevent or mitigate debris accumulations in the future. The debris removal equipment, debris mitigation countermeasures, and monitoring methods should be safe and efficient to implement. Furthermore, the practices should be accepted by ODOT workers and, therefore, end-users must be engaged in the development and testing of potential solutions. To achieve these goals, we engaged in collaborative research with ODOT on the following project objectives:

1) Documented current state-of-the-art debris removal techniques and mitigation practices used by state DOT's and other public or private entities,
2) Assessed ODOT's current knowledge, skills, abilities, and equipment preferences and selected, sourced, and tested debris removal equipment,
3) Evaluated countermeasures to mitigate debris accumulations from forming,
4) Designed, implemented, and monitored debris and scour mitigation countermeasures, and
5) Disseminated knowledge and project outcomes through the production of multi-media education materials to facilitate technology transfer.

Numerous studies have documented approaches to avoid or mitigate accumulations on piers to reduce scour and maintain hydraulic capacity at the bridge opening. Pier shape, span length, bridge clearance, and pier placement outside of the primary drift path are practices that should be implemented at the design phase (Diehl, 1997; Lyn et al., 2007). For piers with multiple columns or exposed piles, Brice et al. (1978)

recommended installation of webbing or complete enclosure to prevent debris from catching between members. Other structural countermeasures attempt to redirect or trap debris before catching on piers. Diehl et al. (1997) identified bank armoring and river training with barbs or bendway weirs to improve flow alignment and reduce debris trapping. Lagasse et al. (2010) identified 1) debris deflectors, 2) debris catchers/basins, and 3) debris fins as practices implemented with widely varying degrees of success. Debris deflectors often consist of sacrificial piles placed upstream of a pier in a v-shaped pattern to redirect debris away from the pier and through the span. Debris sweepers with a rotating drum have been mounted to the upstream face of piers and Lyn et al. (2007) found most installations in Indiana failed within a few years. Debris racks and debris basins are placed across the channel to catch debris before reaching the bridge. Debris fins are extensions of piers that lift and rotate debris but may become snag points that initiate the formation of accumulations (Sheeder and Johnson, 2008; Lagasse et al., 2010). Submerged vanes (i.e. Iowa vanes) and natural channel design structures including rock vanes, cross vanes, and w-weirs are commonly used to align flow, enhance lateral channel stability, provide grade control, and improve instream habitat. Despite having a low profile in the river, research has found vanes to influence flow hydraulics to depths greater than five times the structure height (Johnson et al., 2002). Single-arm vanes and Iowa vanes are viable solutions where debris accumulations form near riverbanks and flow can be realigned away from the pier or abutment towards the center of the span. W-weirs or modified w-weir designs are better suited to mid-channel piers. Techniques to construct vanes and w-weirs can be flexible and numerous materials (e.g. v-interlocking blocks, quarried limestone boulders, properly sized dump rock, waste concrete slabs, etc.) can be utilized depending on site conditions and availability of construction materials. Unfortunately, there is little evidence of vanes being utilized as debris mitigation countermeasures.

2.2 Scour Detection and Bridge Inspection

The overall goal of this phase of the research was to assess the utility of sonar or sounding technologies to enhance routine inspection of underwater bridge components. The research focused on bridges over larger streams and rivers with water depths >5-feet. These conditions present difficulties for bridge inspectors to make thorough evaluations of the subsurface structure conditions and riverbed bathymetry through visual assessments or direct physical contact via manual probing. Remote, non-contact methods to access sites and collect data were prioritized. As a result, the Ohio Uncrewed Aircraft Systems (UAS) Center was engaged in the research as they would serve as the ultimate end-user of the equipment and data provider to ODOT District Bridge Engineers and Inspectors. To achieve these goals, we completed the following overarching project objectives:

6) Conducted listening sessions with bridge engineers and inspectors to identify challenges in the bridge inspection process and define data needs,
7) Identified and characterized typical site conditions where remote sensing technologies are needed,

8) Identified technology solutions, including hardware, sensors, and software, and organized onsite technology demonstrations with vendors, and
9) Made final technology and data collection/processing recommendations and sourced equipment for further testing.

Sounding and sonar technologies offer the advantage of reduced inspection time and associated costs. The efficiency of sonar inspections stems from its ability to collect data rapidly, covering large areas in a single pass. Additionally, the non-invasive nature of sonar means that there is no need for divers or crewed equipment, further streamlining routine inspection processes. Furthermore, bridge inspections can be hazardous, especially when involving swift water or piers with accumulated debris that creates dangerous flow hydraulics. Sonar technology minimizes the need for inspectors to physically access risky areas. This reduction in human exposure to dangerous conditions enhances safety for inspection teams and contributes to a more efficient assessment process. The ability of sonar to provide detailed, repeatable data collection makes it an excellent tool for long-term monitoring and change detection. By comparing sonar images taken over time, inspectors can track the progression of defects, assess the effectiveness of maintenance efforts, and make informed decisions about repair and rehabilitation strategies.

3. Research Approach

3.1 Debris Removal and Mitigation

To identify current state-of-the-art debris removal techniques, we utilized a combination of literature review from academic and non-academic sources and outreach to peer groups (e.g. Transportation System Preservation Technical Services Program; (TSP2)) focused on bridge preservation. A description of the research project goals was communicated to TSP2 members via email, and a request was made to share current methods and examples of debris removal strategies currently in use in their state. Responses were ultimately gathered from seven states (CT, IL, IN, KY, MI, MN, and OR) which identified eight unique debris removal strategies. Additionally, we evaluated equipment and techniques from the agricultural, forestry, mining, shipping, and construction industries to identify other potential solutions that might be adapted for removing debris.

Concurrent to research on debris removal methods, we made site visits to ODOT garages and conducted in-person interviews with ODOT district and county staff to inventory equipment and gauge operator skills and ability to work in a river environment. Our interviews included questions on current and past methods of debris removal, sought out reasons why certain debris removal methods may have been successful or abandoned, requested ideas for improvements, attempted to identify potential barriers to implementing any new approaches, and asked staff to identify criteria critical to a workable solution.

After a debris removal equipment solution was identified, sourced, and evaluated in the field, data were collected on the cost and time to complete debris removal projects with the new approach. Equipment, labor and indirect costs per project were provided by ODOT District 8 Highway Management Administrator and several County Transportation Managers to estimate costs for projects completed internally by ODOT crews and provide a comparison to projects executed externally by contractors.

To identify debris mitigation methods, we conducted a review of the academic, industry, and agency literature including project reports from Army Corps of Engineers and consulting firms who perform work in big river environments. Mitigation measures were discussed with ODOT engineers and environmental staff, and the research team evaluated materials, methods, and costs for construction. Once suitable approaches were identified, the research team performed more advanced hydrology and hydraulic analyses using the Surface-Water Modeling System (SMS; Aquaveo) user interface with the Sedimentation and River Hydraulics (SRH-2D; Bureau of Reclamation) model and the Hydraulic Engineering Center – River Analysis System (HEC-RAS; U.S. Army Corps of Engineers) software. Hydraulic analysis reports and engineering drawings for a series of chevron vane structures were provided to ODOT and their consultant (Carpenter Marty Transportation) who were designing a bridge rehabilitation project at State Route 122 over the Great Miami River in Middletown, OH. The vanes and pier protection were installed by a contractor and monitored post-construction by the research team using a mix of qualitative observations, bridge mounted cameras for non-contact monitoring during flood events, aerial imagery, a drone-based echosounder, and bathymetric surveys conducted from a boat using a GPS device for horizontal positioning; a surveyors rod, and USGS gauge data with water surface elevation as a reference height for vertical positioning.

The research team also worked with ODOT engineers to redesign a scour mitigation countermeasure, a cross-vane structure, located at State Route 52 over Ray Run in Clermont County, OH. The bridge abutments at this site were subject to scour and degradation was occurring along the streambed downstream of the bridge which had exposed a utility pipe crossing the stream outside of the road right-of-way. The research team conducted hydraulic analysis using SMS SRH-2D and developed a conceptual design for ODOT engineers and environmental scientists who developed engineering plans and completed permitting requirements. The project was built by ODOT forces from the Clermont County garage.

3.2 Scour Detection and Bridge Inspection

A focus group meeting with bridge engineers and inspectors was coordinated to identify typical site characteristics that make bridge inspection and data collection difficult or unsafe. Additionally, bridge engineers and inspectors were asked to identify real examples of difficult bridges with supporting documentation for their most problematic inspection sites. In total, 7 ODOT Districts provided 22 total examples of sites with challenging conditions for traditional inspection methods. Bridge photos and bridge inventory information were gathered from ODOT databases to better understand bridge and site characteristics. Recent bridge inspection reports were provided for most projects. Bridge inspection reports typically included detailed results of dive inspections which included presence of submerged debris, pier conditions, and presence or absence of scour and voids under pier and abutment foundations.

After identifying challenging site conditions and information needs, the research team conducted a review of the literature and online sources of information to identify various technology solutions including sensors deployed from aerial drones and remote control or autonomous surface water vehicles with integrated sonar. In total, 19 manufacturers of single and multibeam sonars were evaluated. Information on sonar frequencies, operating depths, field-of-view, horizontal and vertical beam width, number of beams, beam spacing, swath width, resolution, accuracy and cost were evaluated for 67 sonar models. Aerial and surface water platforms were also evaluated to deploy the sensors. From the list of candidate systems, three systems were selected for further testing at State Route 127 over the Great Miami River near New Miami, OH. The Ceasar Creek Lake was utilized as a backup location for one demonstration when river stage and current velocities were too high in the river for a safe and effective technology demonstration. During the demonstrations, vendors covered mission planning and data processing software.

4. Research Findings and Conclusions

4.1 Debris Removal and Mitigation

4.1.1 Objective 1 – Current State-of-the-Art Debris Removal Methods

Debris removal methods in other states included heavy duty work boats and barges which were primarily utilized in deep water scenarios that could accommodate significant boat draft. Several states had utilized boom trucks or heavy-duty rotators but indicated that workers rigging large debris in the river was a safety concern and removal of smaller debris was slow and tedious. Several states, including Ohio, had utilized cranes with clamshell buckets but operator visibility of target debris was a concern as was removal from bridges with overhanging, hammerhead piers. Several states, including Ohio, have utilized long reach excavators; however, the geometry of a two-piece boom and stick over the parapet wall restricted movement and attack angles and thus limited ability to reach debris at the front of the pier. Variable angle booms (i.e. three piece inner and outer boom and stick) and other stick attachments were explored as an opportunity to increase the reach and precision of these excavators. One state had utilized a cable yarder system adapted from the forestry industry; however, logistics for deploying this equipment at numerous sites with limited access was a concern for most sites in Ohio. Two states, including Ohio, had trialed articulating boom cranes (i.e. knuckleboom crane) with a grapple; however, reduced lift capacity and potential for machine tipping due to limited ability to deploy outriggers was a concern. Additional methods that were identified included a walking (spider) excavator with pontoons and aqua stilts for stability when working in water have been used in shallow water dredging projects around the world. Construction mats have also been used in aquatic environments; however, in Ohio any equipment contact with the streambed often triggers an environmental process due to the presence and protection of mussel species in many rivers around the state.

4.1.2 Objective 2 – Assess Current Inventory and Worker Preferences and Select, Source, and Evaluate Debris Removal Equipment

Current equipment in ODOT inventory was primarily limited to medium sized excavators and service trucks with small lift booms and winches. A few pieces of specialized equipment including a long-reach excavator, a two-piece knuckleboom crane, and lattice boom crane were available in a single district and could be shared statewide. Workers and environmental staff indicated a strong preference for equipment solutions that could be deployed from the bridge deck to improve worker safety and reduce permitting requirements associated with working in the stream. Equipment operators indicated willingness to learn and obtain certifications for operating new types of equipment, if needed.

Ultimately, the research team in collaboration with ODOT selected and sourced a custom knuckleboom crane (Figure 1) designed by Palfinger USA for debris removal below the bridge deck. The new design addressed the shortcomings of a two-piece crane by adding a jib section. In the three-section design, the inner boom section could rotate and reach beyond the parapet wall, the outer boom section could extend vertically, and the jib section could extend and reach below the bridge deck (Appendix Figure 2). Additionally, a 12,000-lb counterweight system (Appendix Figure 3) was incorporated into the truck bed to offset lifting forces when the outriggers could not be fully deployed while maintaining ~97% of full lifting capacity. The stability control system software on the crane was updated to account for scenarios with partially deployed outriggers. In addition, a grapple saw attachment was included so that debris could be cut to a manageable size, if needed.

Figure 1: Knuckleboom crane with safety software to prevent overloading when outriggers cannot be fully deployed. The inset picture in the lower right shows the custom 12,000-lb counterweight system that shifts away from the working side of the crane to offset impact of partially deployed outriggers to maintain lifting capacity of the crane.

Work orders were obtained to evaluate debris removal costs utilizing the new equipment with ODOT crews. Small projects typically completed by ODOT realized a 43% reduction in labor when using the knuckleboom crane compared to other debris removal methods. Average debris removal costs were $3,534 per site for 21 sites evaluated in detail, compared to $25,330-$69,110 when completed by external contractors (Table 1 Appendix A). This represented a ~80-95% cost savings. Furthermore, typical projects could be completed in 1-2 weeks or less when permitted and performed by ODOT forces compared to 8-12 months or more for work that was sold to contractors and consultants. To date, approximately 60 sites have been cleared of debris and the ROI for the equipment was <1-year. Moreover, additional uses for the crane have been identified included removal of spalled concrete from bridge faces, placement of culverts and rock channel protection, and installation of signage. These types of work have been completed on 18 projects to date.

4.1.3 Objective 3 - Evaluate Debris Mitigation Countermeasures

A review of the literature suggested that debris deflectors, sweepers, racks, basins, and fins often required significant maintenance with limited effects on debris. Therefore, focus was placed on natural channel design practices which should be more self-sustaining. In addition, the research team and ODOT had previously collaborated on implementing these practices in smaller stream systems with success.

Given debris accumulations were occurring on mid-channel piers, the w-weir concept was adapted to create a series of chevron vanes across the thalweg of the channel where debris tended to accumulate at the upstream edge of piers. SMS modeling results indicated that the vanes would concentrate flow and increase flow velocities to the clear spans between bridge piers. Modeling also suggested that the alignment of flow would be improved and likely reduce formation of sand bars and eddies downstream of the bridge which reduced flow velocities and promoted debris snagging on upstream piers. Increased flow velocities through the bridge spans would also likely lead to deeper bedforms and water depths thus reducing risk for debris dragging and accumulation along the streambed.

4.1.4 Objective 4 - Implementation/Monitoring of Debris/Scour Countermeasures

The chevron vanes (Figure 2; and Appendix A Figures 4 and 5) were constructed in early 2022 as part of a bridge rehabilitation project. The project already required the construction of temporary access fill to dredge the channel and replace the bridge bearings. The additional work to install the vanes cost ~$400,000. To date, the project has greatly reduced, but not fully eliminated, debris accumulations. After large storm events, ODOT crews have utilized the knuckleboom crane to remove small amounts of debris at the piers. However, collectively, the chevron vanes and crane have mitigated debris accumulation at the site which has historically been extensive (Figure 6 Appendix A).

Post-construction monitoring at the site has included aerial imagery, bridge mounted cameras, boat surveys with GPS, and a single beam sonar echosounder tethered to an aerial drone. Results suggest that flow alignment has improved, flow velocities to the clear span are increased relative to piers, and predicted bedforms have developed and been maintained to date.

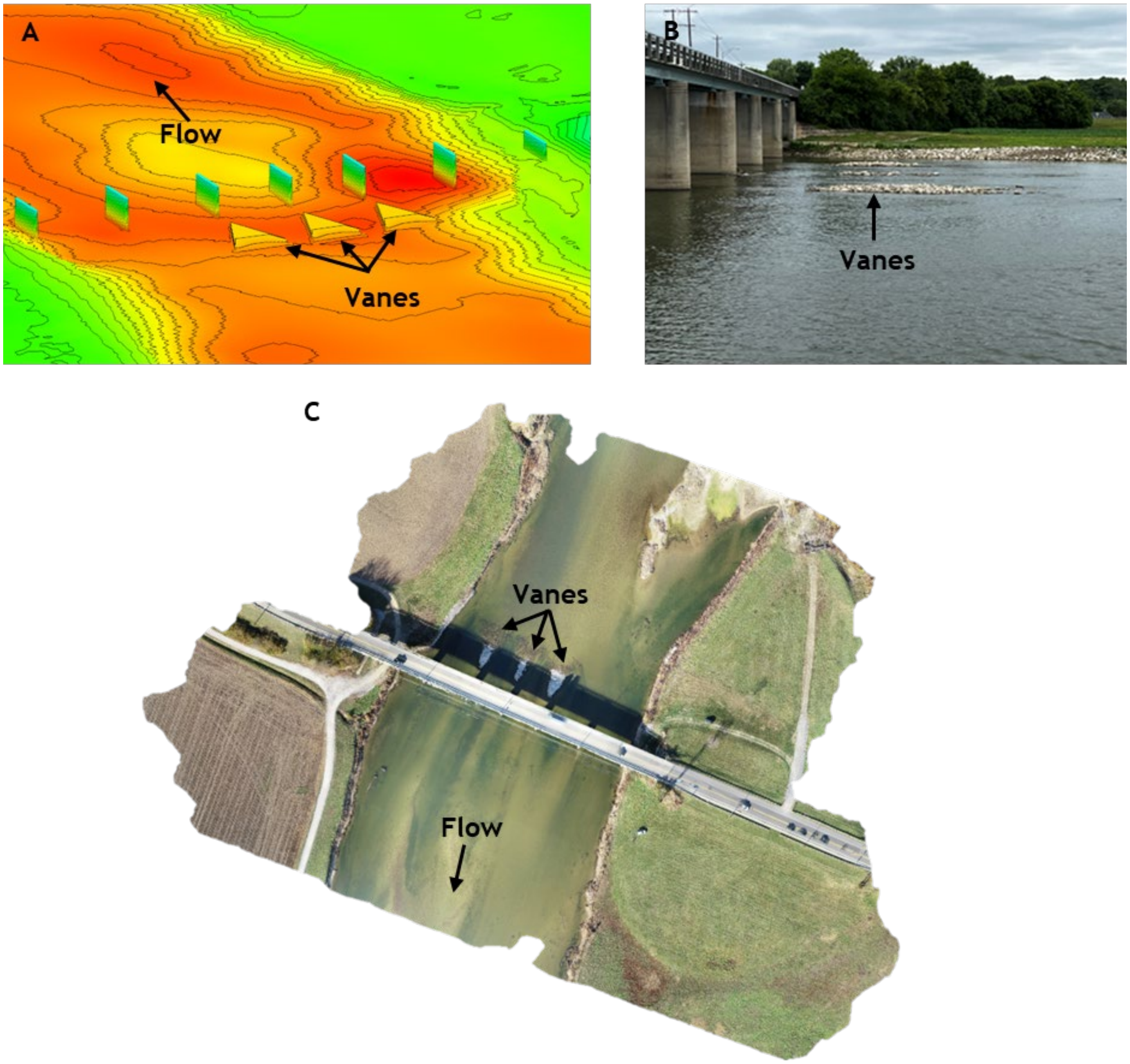


Figure 2: A) Computer model of proposed chevron vanes at State Route 122 over the Great Miami River superimposed on topographic and bathymetry data. B) Side view of constructed vanes above water level. C) Planform view of installed chevron vanes.

The cross-vane project to mitigate scour and bed degradation at Ray Run in Clermont County was completed in autumn 2022 (Figure 3). The structure was placed beneath the bridge deck, an innovative solution driven by limited access of road right-of-way (ROW) to place the structure. The bridge was inspected by ODOT in April 2024 and only minor scour (Figure 7 Appendix A) at one upstream abutment was detected and streambed degradation had been mitigated despite numerous significant flood events. In addition, the exposed utility pipe at the downstream end of the project had filled in and was therefore protected from damage.

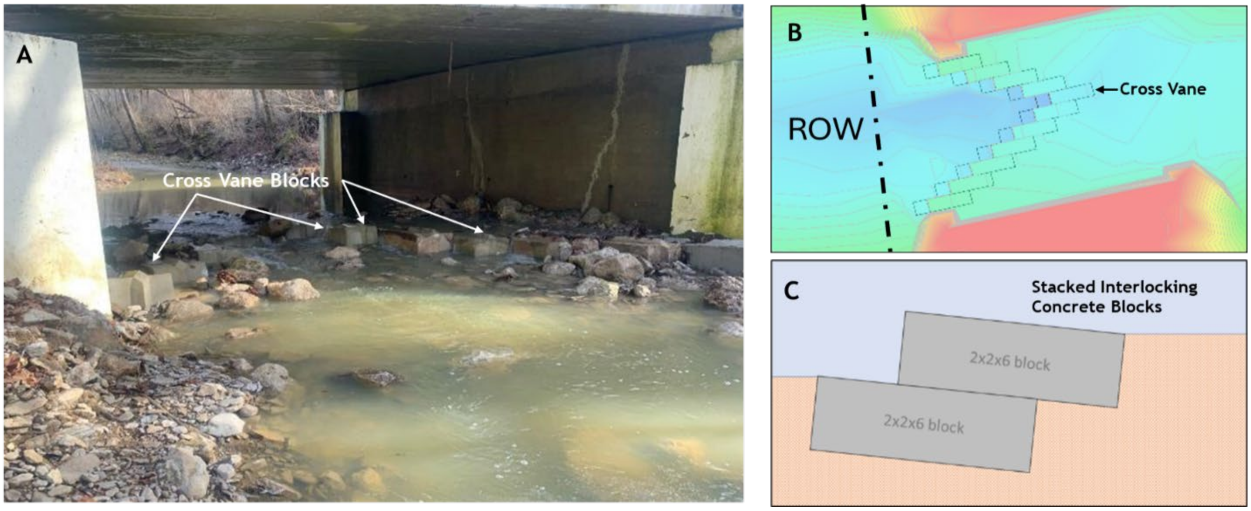


Figure 3: A. Photo of cross vane structure at Ray Run looking upstream. B. Planform view of cross vane. C. Longitudinal view of stacked 2’x2’x6’ interlocking concrete blocks used to construct the cross vane at Ray Run.

4.1.3 Objective 5 – Disseminate Project Outcomes and Technology Transfer

Research results and lessons learned have been shared through multiple channels. Findings from debris removal research were shared through the No Boundaries – Transportation Maintenance Innovations program which is a national collaboration funded through a Transportation Pooled Fund study (TPF-5(441)). Online resources about the research can be found at: https://maintainroads.org/innovation-database/entry/162/ and a joint presentation from ODOT collaborators and the research team can be accessed at: https://vimeo.com/653715691.

Debris mitigation and scour countermeasures research was highlighted through the NCHRP 20-44(28) National Cooperative Highway Research Program - Implementation Support Program. The program highlights select projects with high potential for implementation and attempts to increase awareness. The primary landing page is here: https://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=4921. An overview of the practices is here: https://vimeo.com/763749049/c0e1c2b421, and a more detailed presentation is here: https://vimeo.com/813311740/1871232eda.

4.2 Scour Detection and Bridge Inspection

4.2.1 Objective 6 – Conduct Listening Sessions to Identify Needs

The focus group meeting with bridge engineers and inspectors revealed that detection of scour and voids around piers and abutments were the primary concern for sites that could not be accessed by wading. Detection of submerged debris was also a concern when sites needed to be cleared for dive inspections. Additionally, the need to establish cross sections in the vicinity of the bridge to detect changes through time was a particular challenge with current equipment and methods.

4.2.2 Objective 7 - Characterize Sites with Difficult Inspection Conditions

District bridge engineers identified 22 sites across the state with conditions that made inspections difficult. The average and median maximum depth across sites were 16.6-ft and 10.5-ft, respectively. The range of maximum depths spanned 4.7-ft to 74.0-ft. Current velocities during the most recent dive inspections at these sites were <1.0-ft/second except at one site where the current velocity was ~2.5-ft/second. These findings provided insights into the operating characteristics of the remote vehicle and sonar characteristics required to inspect these sites.

4.2.3 Objective 8 - Identify Technology Solutions and Coordinate Demonstrations

Following evaluation of sonar technologies and remote vehicles, three companies were selected for further testing. The first option included the Yellow Springs Instruments (YSI) Hycat Uncrewed Surface Vehicle (USV) outfitted with the Sontek M9 and YellowFin side-scan sonars. The second option was the Seafloor EchoBoat 160 with SeaRay multibeam sonar. The final option was the Maritime Robotics Otter Pro vehicle with Norbit iWBMS-Ekinox multibeam echosounder. These options provided a range of sonar capabilities that met the minimum project requirements and had variable price points. Two of the vehicle platforms were catamaran style platforms while the Seafloor was a single hull vehicle.

During the demonstrations, each of the companies utilized proprietary software for mission planning which offered similar levels of functionality. In terms of data processing, all companies recommended Applanix POSPac for Mobile Mapping Sensors (MMS) for GPS corrections and integration with inertial management unit (IMU) sensor data used when GPS signal was lost beneath the bridge deck. Sonar data was processed and integrated with GPS data using the Hypack Hysweep software from Xylem. The Hysweep software allowed for filtering and editing of point cloud data and extraction of 2D and 3D bathymetry.

The Seafloor EchoBoat 160 performed efficiently in the field and collected the most extensive dataset amongst all the demonstrated technologies. Data processing was similar amongst across brands; however, the Seafloor SeaRay sonar provided the highest quality output and most detailed imagery (Figure 4). Submerged debris, rock channel protection, sand dunes along the bed, and scoured areas along a pier were easily identifiable in the processed data. Given the Seafloor EchoBoat and SeaRay sonar were the least costly technology option, this package was selected and sourced for further testing.

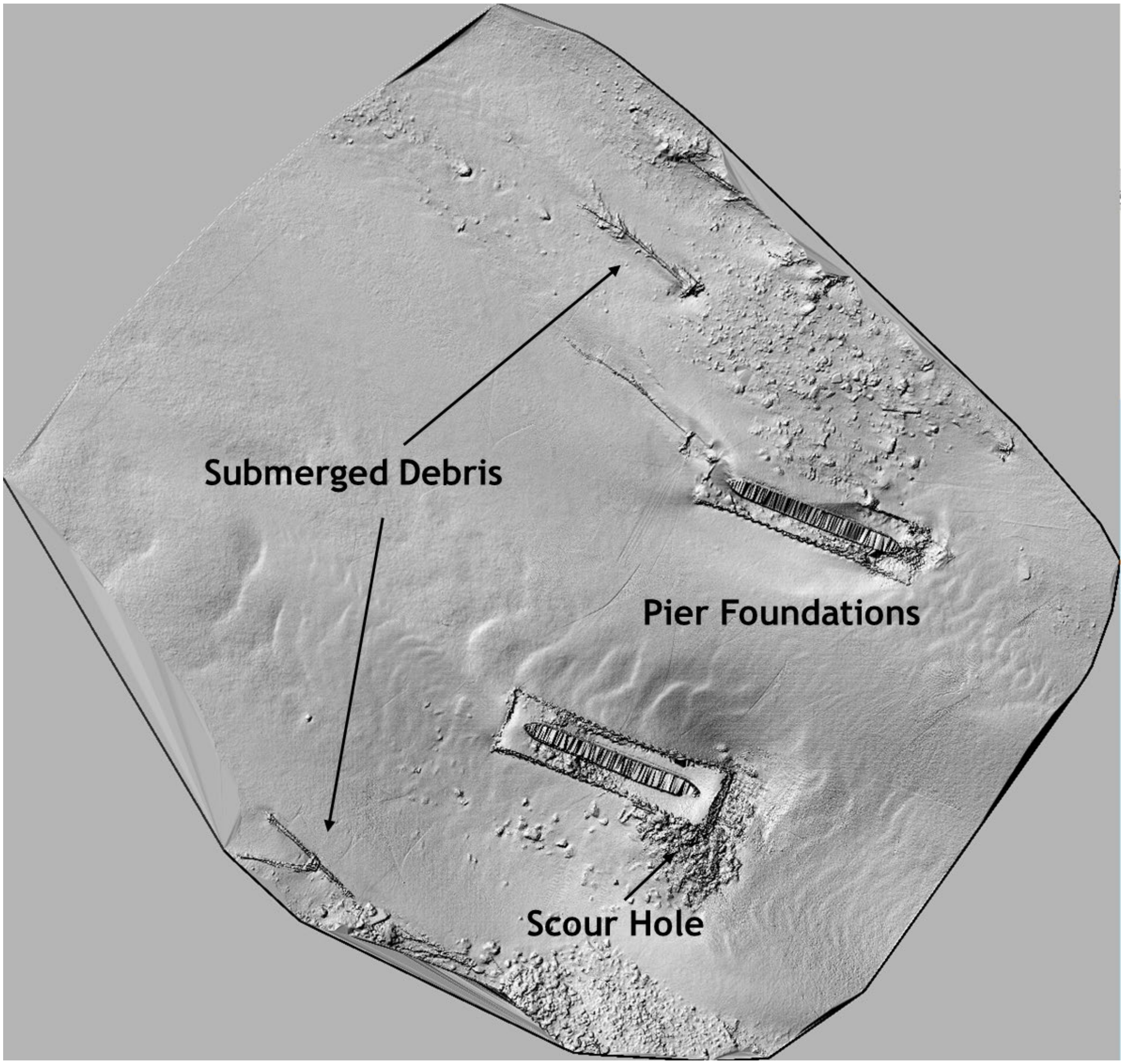


Figure 4: Processed sonar data from the Seafloor EchoBoat and SeaRay sonar system.

4.2.4 Objective 9 – Source Technology and Conduct Field Tests

The Seafloor system was purchased and is currently being field deployed for further evaluation.

5. Recommendations for Implementation

5.1 Debris Removal and Mitigation

Debris removal via the knuckleboom crane has proven to be a superior approach to other methods used previously in ODOT District 8. Most importantly, worker safety is greatly enhanced over hand methods of debris removal with chainsaws. The approach removes the operator from unstable debris piles and away from potentially dangerous river currents. It is also an advancement over other mechanical methods of debris removal due to the geometry of the three-piece boom and remote operation capabilities. Other mechanical methods such as the lattice boom crane and long-reach excavator require an operator in the machine being guided by spotter over radio or by hand signals. In addition, the integrated counterweight system and stability control system allows the truck and crane to partially deploy outriggers which can reduce road closures to a single lane thus limiting traffic delays and detours with fewer impacts to motorists. Inclusion of a grapple saw allows for debris to be cut to a manageable size and less likely to cause problems at other bridges as it migrates downstream.

Given the built in safety systems on the crane, the biggest risk would be operation of the machinery during flow conditions with high current velocities or operation by an unqualified operator. High current velocities could be problematic when the crane has secured large debris in the grapple and movement into the river current exerts large and unexpected forces that exceed the capabilities of the machine. An unqualified or untrained operator presents a risk as they may not understand the limitations of the machine or how to avoid risky situations that may damage the crane or injure workers. Currently, operators are required to complete extensive training through the National Commission for the Certification of Crane Operators and pass certification for Articulating Boom Cranes to mitigate risk.

The ROI on the machine was <15 projects when considering the cost of doing projects internally with ODOT forces compared to external vendors. Approximate cost savings were ~80-95% with the new approach. The ROI depends on frequency of use but the breakpoint threshold for this machine was met within months of delivery. Overall, the ROI, improvements to worker safety, timeliness and quality of work suggest that this approach should continue to be shared with other Districts where debris accumulation on bridge piers is a concern.

Debris and scour mitigation projects can greatly reduce the frequency of maintenance and often resolve recurring problems. Smaller projects such as the Ray Run cross vane can be implemented inexpensively and typically are robust and sustainable solutions. The benefits of larger and more expensive projects that cannot be implemented by ODOT forces such as the Great Miami River at State Route 122 are more difficult to determine. In some regards, the project has greatly reduced the frequency and severity of debris accumulation; however, the knuckleboom crane is a tool that allows for regular and more timely debris removal. Hydraulic structures in large rivers should likely be limited to sites that have frequent, recurrent, and extensive debris accumulations or are difficult, expensive, or dangerous to access on a regular basis. Given climate variability, the limited number of sites, short duration, and lack of a control site it is not possible to calculate a defendable ROI for these projects for the purpose of debris mitigation.

5.2 Scour Detection and Bridge Inspection

Scour detection and bridge inspection with sonar deployed via GPS enabled USV can greatly enhance scour detection, underwater bridge inspection, and hydrographic survey capabilities. Prior to this project, inspection work may have been contracted out to consultants with large and complex bridges costing tens of thousands of dollars or more. Moreover, with internal capacity critical projects may be completed in a timelier manner with less administrative burden. Assuming a modest cost savings of $10,000 per project suggests that the ROI breakpoint would be reached in 20-30 projects given the cost of the technology. The benefit will likely be determined by the willingness and availability of the Ohio UAS Center to support data collection regularly. At this time, it is not advisable to replicate the technology as the current system should provide statewide coverage for bridge inspection. This may be reconsidered if additional use cases are identified and demand increases.

The larger risk to deploying the sonar technology is use in difficult river conditions or around debris piles where tipping or snagging are a potential issue. The main compartment of the vessel is sealed and should protect internal electronics; however, external GPS antennae are not waterproof when submerged and could be damaged if the vessel capsizes.

6. Bibliography

Bowman, M. and L. Moran. 2015. Bridge preservation treatments and best practices. Publication No. FHWA/IN/JTRP-2015/22.

Bradley, J., Richards, D. and C. Bahner. 2005. Debris control structures – evaluation and countermeasures. Hydraulic Engineering Circular 9, 3rd Edition. Report No. FHWA-IF-04-016-HEC-9

Diehl, T. 1997. Potential drift accumulation at bridges. Publication No. FHWA-RD-97-028.

Johnson, P., Sheeder, S. and J. Newlin. 2010. Waterway transitions at US bridges. Water and Environment Journal 24: 274-281.

Lagasse, P., Clopper, P., Zevenbergen, L., Spitz, W. and L Girard. Effects of debris on bridge pier scour. 2010. NCHRP Report #653. The National Academies Press. Washington D.C.

Lyn, D., Cooper, T., Condon, C. and L. Gan. 2007. Factors in debris accumulation at bridge piers. Publication No.: FHWA/IN/JTRP-2006/36.

Pangallo, J.D., Gray, Teresa, Land, Walter, and Toillion, S.E., 1992, Bridge span lengths for passage of drift: Indianapolis, Indiana Department of Transportation, 11 p.

Sheeder, S. and P. Johnson. 2008. Controlling debris at Pennsylvania bridges. The Thomas D. Larson Pennsylvania Transportation Institute. Contract #510602.

7. Appendix A

Appendix A Figure 1. A) Lattice boom crane with clamshell bucket, and B) long reach excavator for debris removal.

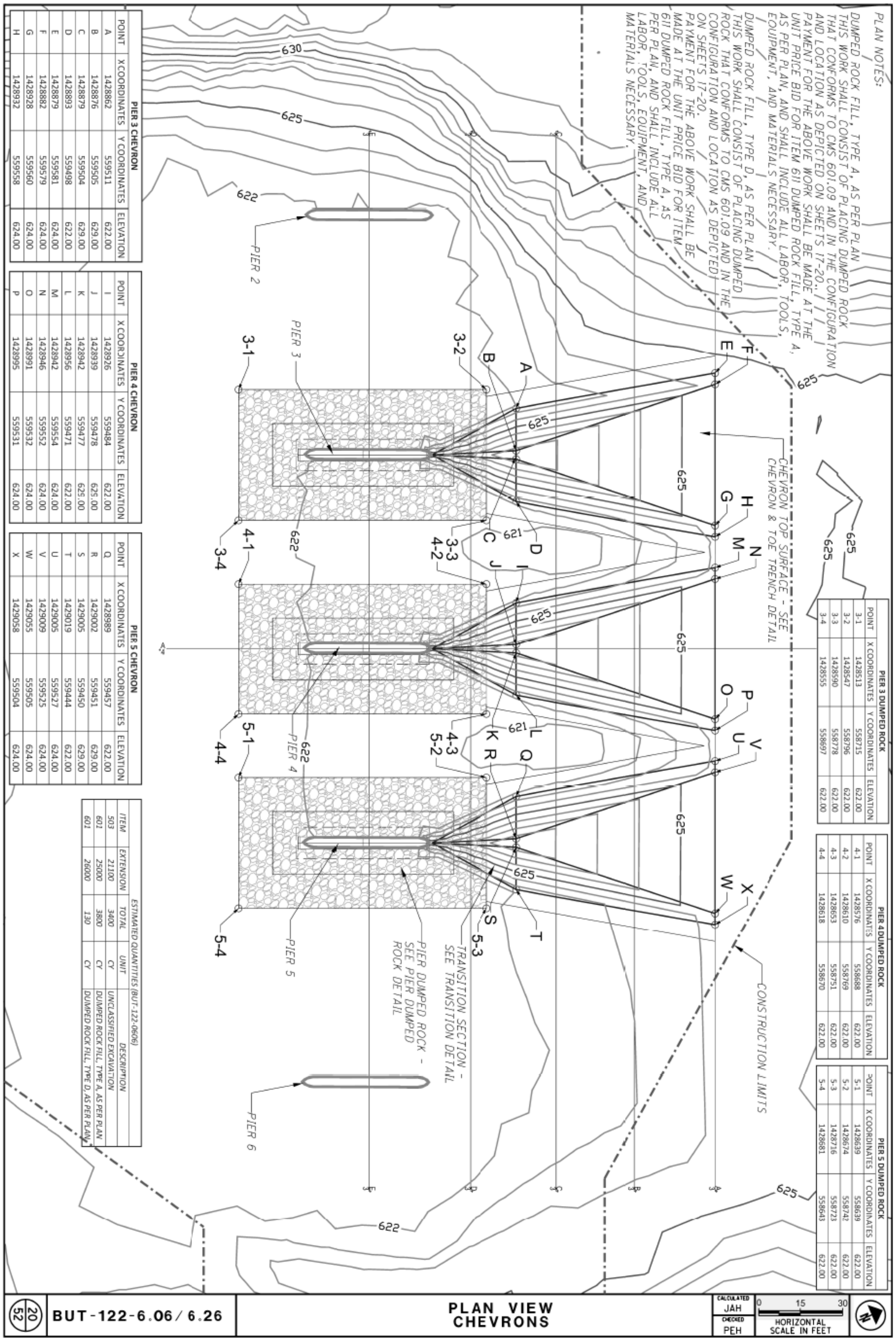
Appendix A Figure 2. Knuckle boom crane reaching below the bridge deck on a tee type pier.

Appendix A Figure 3. Movable counterweight system on knuckle boom truck bed.

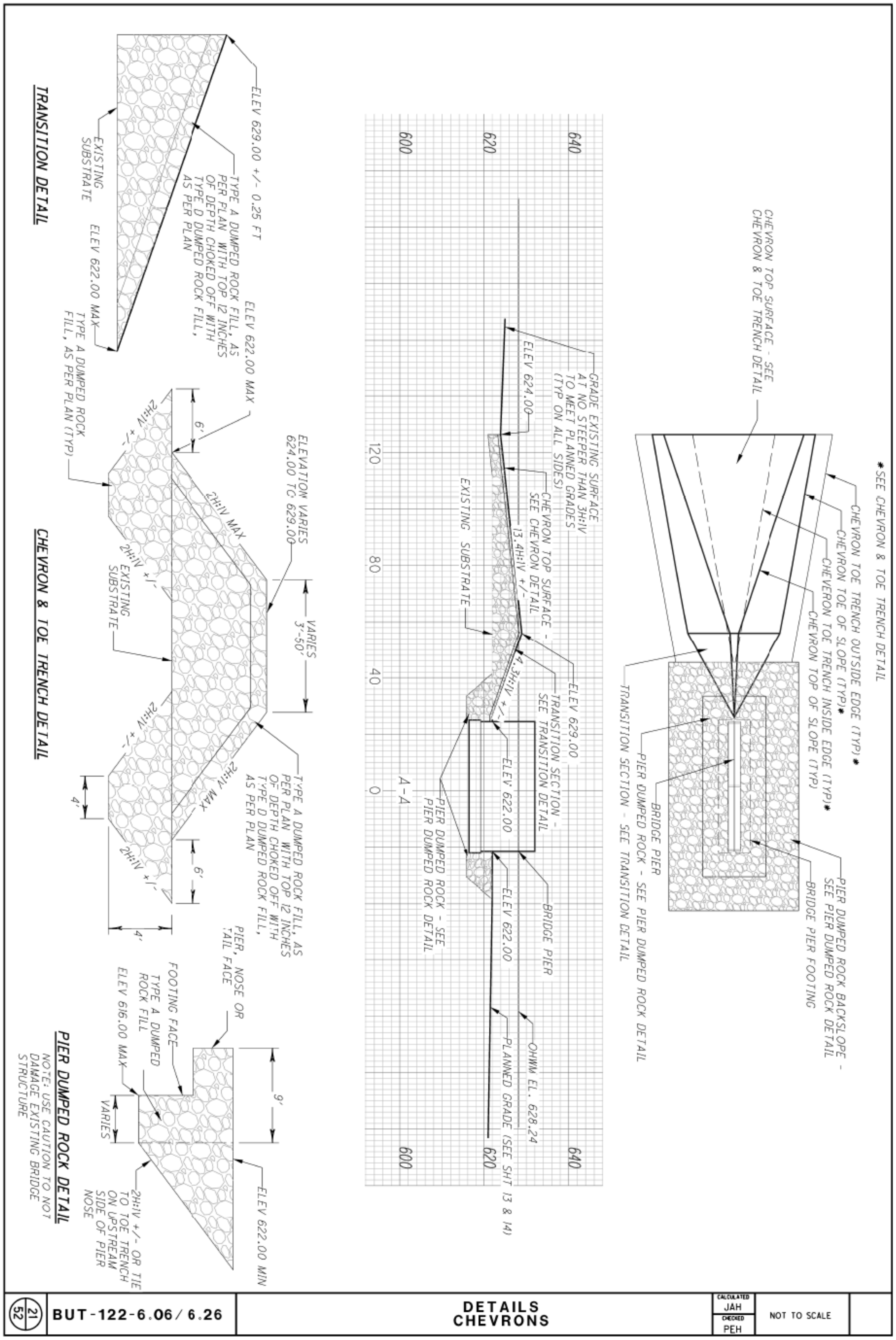
Appendix A Table 1. Projects listed in ODOT TIMS under the Primary Work Category of Debris Removal. PIDs were cross-checked with information from ELLIS to determine final project costs.

Fiscal Year	District	PID #	# of Bridges	Cost[1] ($)	Cost per Site[1]	Inflation Adjusted Cost[2] ($)
2005	11	78551	2	$83,500	$41,750	$69,110
2007	12	81780	16	$275,000	$17,190	$26,800
2008	8	83516	10	$169,400	$16,940	$25,330
2019	9	107348	9	$248,552	$27,620	$34,630

1 – Cost per site based on values reported in ODOT ELLIS database and number of sites reported in TIMS.
2 – Inflation adjusted to Oct-2024 using Bureau of Labor Statistics CPI Inflation Calculator.



Appendix A Figure 4. Planform view of engineering plans for chevron vanes at State Route 122 over the Great Miami River in Middletown, OH.



Appendix A Figure 5. Engineering details for chevron vanes installed at St State Route 122 over the Great Miami River in Middletown, OH.

Appendix A Figure 6. Debris accumulation at State Route 122 over the Great Miami River.


Appendix A Figure 7. Bridge foundation at State Route 52 over Ray's Run in Clermont County, OH.