

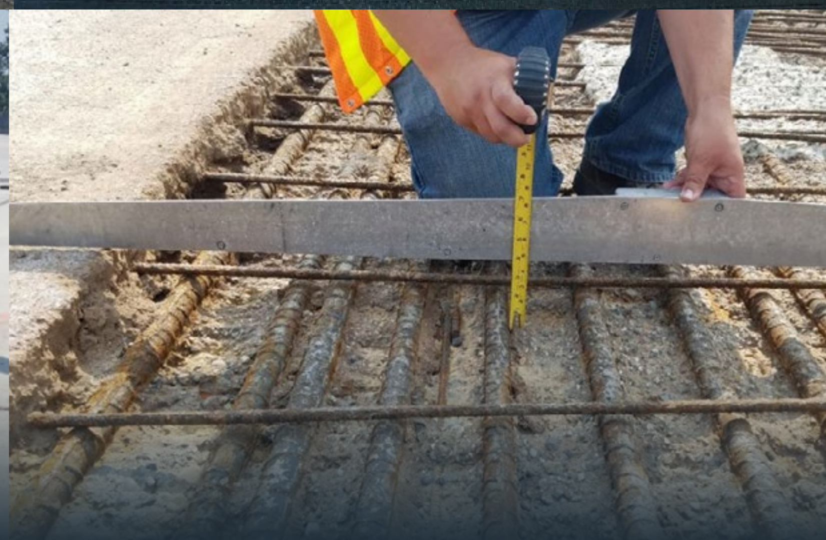

SCAN TEAM REPORT

NCHRP Project 20-68A, Scan 18-01

Successful Approaches for the Use of Hydrodemolition for Partial Depth Removal of Bridge Decks

Supported by the

National Cooperative Highway Research Program

The information contained in this report was prepared as part of NCHRP Project 20-68A U.S. Domestic Scan, National Cooperative Highway Research Program.

SPECIAL NOTE: This report IS NOT an official publication of the National Cooperative Highway Research Program, Transportation Research Board, or the National Academies of Sciences, Engineering, and Medicine.

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The purpose of each scan, and of Project 20-68A as a whole, is to accelerate beneficial innovation by facilitating information sharing and technology exchange among the states and other transportation agencies and identifying actionable items of common interest. Experience has shown that personal contact with new ideas and their application is a particularly valuable means for such sharing and exchange. A scan entails peer-to-peer discussions between practitioners who have implemented new practices and others who are able to disseminate knowledge of these new practices and their possible benefits to a broad audience of other users. Each scan addresses a single technical topic selected by AASHTO and the NCHRP 20-68A Project Panel. Further information on the NCHRP 20-68A U.S. Domestic Scan program is available at http://144.171.11.40/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=1570.

This report was prepared by the scan team for Domestic Scan 18-01, *Successful Approaches for the Use of Hydrodemolition for Partial Depth Removal of Bridge Decks*, whose members are listed below. Scan planning and logistics are managed by Arora and Associates, P.C.; Harry Capers is the Principal Investigator. NCHRP Project 20-68A is guided by a technical project panel and managed by Andrew C. Lemer, PhD, NCHRP Senior Program Officer.

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Disclaimer

Scan 18-01

Successful Approaches for the Use of Hydrodemolition for Partial Depth Removal of Bridge Decks

REQUESTED BY THE

American Association of State Highway and Transportation Officials

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February 2020

The information contained in this report was prepared as part of NCHRP Project 20 68A U.S. Domestic Scan, National Cooperative Highway Research Program.

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Abbreviations and Acronyms

AASHTO	American Association of State Highway and Transportation Officials
BSIR	Bridge Safety Inspection Report (Michigan DOT Case History)
DOT	Department of Transportation
FHWA ITD	Idaho Transportation Department
LaDOTD	Louisiana Department of Transportation and Development
LMC	Latex-Modified Concrete
MDOT	Michigan Department of Transportation
MOT	Maintenance of Traffic
NCHRP	National Cooperative Highway Research Program
PennDOT	Pennsylvania Department of Transportation
PSI	Pounds per Square Inch
ROW	Right of Way
SFMC	Silica Fume Modified Concrete (Michigan DOT Case History)
SR	State Route
SY	Square Yard
TRB	Transportation Research Board
VE	Value Engineering

Executive Summary

This report summarizes the findings from the scan "Successful Approaches for the Use of Hydrodemolition For Partial Depth Removal of Bridge Decks." The purpose of the scan was to investigate and exchange information with users of hydrodemolition to document their specific applications. The team examined case studies of bridges undergoing hydrodemolition as well as bridges that have undergone past hydrodemolition deck replacements to examine both the process and long-term performance of bridges that have been subject to a partial deck replacement involving hydrodemolition. The team explored various aspects of the hydrodemolition process, gathering perspectives of agencies, contractors, and consultants experienced in hydrodemolition.

A scan team consisting of representatives from state DOTs, the Federal Highway Administration (FHWA), and the American Association of State Highway and Transportation Officials (AASHTO) was formed to guide the scan and develop findings, recommendations, and implementation actions. Cheryl Hersh Simmons, Chief Structural Engineer, Utah DOT, chaired the scan team.

This scan team met with users of hydrodemolition and documented their specific applications. The team examined not only bridges recently undergoing hydrodemolition but also bridges that have undergone past hydrodemolition deck replacements to study both the hydrodemolition process and long-term performance of bridges that have been subject to a partial deck replacement. The team explored various aspects of the hydrodemolition process, gathering perspectives of agencies and contractors experienced in hydrodemolition. The team specifically focused on how DOTs determined applicable candidates for hydrodemolition, specified construction requirements, and evaluated performance.

The topics were organized into the following thematic areas:

- Decision matrix that leads to the most appropriate action for the bridge deck
- Design criteria and details, construction specifications and staged-construction approaches utilized on projects specifying hydrodemolition
- Wastewater permitting, control, collection, reuse or disposal
- Special considerations regarding reinforcement steel location and protection, existing patch materials, other existing or latent field conditions or damage caused by the operation
- Limitations regarding removal depths if any
- Preferred materials for the deck itself and/or overlays to replace deteriorated concrete removed during hydrodemolition
- Relative costs for design, construction, maintenance, and inspection of bridges which have been subject to hydrodemolition
- Lessons learned and suggestions for improvement

Conversations with various DOTs reinforced the fact that hydrodemolition has been successfully used in multiple states for many years, and multiple states have mature specifications for hydrodemolition. Of the states participating in the scan, three mentioned that there is no major obstruction to use of this method, that it is standard practice, is widely used based on cost and deck condition, and specifications are regularly updated to keep up with current practice. Two of the participating states, environmental concerns and noise issues were a common problem. The shortage of qualified contractors is a roadblock as is a lack of knowledge and training, standard practices guidance, and contract enforcement methods. Other concerns included cost of mobilization, unknown durability, benefit for life-cycle costs, limited budgets, and water availability.

Based on discussions during the scan several of the high-level conclusions regarding Hydrodemolition the team came to include:

- Hydrodemolition can be an effective tool for a bridge preservation program.

Hydrodemolition is most cost-effective when utilized in combination with mechanical removal methods for the initial surface preparation.

- Hydrodemolition should be utilized as part of a holistic deck preservation program.
- Monitoring deck condition and implementing hydrodemolition at the right time is important to achieving a deck that can achieve multiple "lives."
- Multiple states have mature deck preservation programs incorporating hydrodemolition; these should serve as starting points for other states.
- The use of hydrodemolition can be considered mature and practice-ready based on the experiences of the agencies participating in the scan, and there are existing practices for ensuring quality.

Finally, the scan team identified and is pursuing an extensive set of outreach activities to disseminate the scan's findings. These include

- Documenting presentations from states in a concise but complete report.
- Promoting and describe hydrodemolition via technical webinars.
- Make presentations to various AASHTO committees and other professional conferences to further promote the adoption and use of hydrodemolition.
- Investigate the possibility of developing Internet-based tools for gathering information from bridge owners on their experiences and practices in using hydrodemolition.
- Identify additional knowledge gaps beyond those disclosed as a part of this peer exchange, with the goal of developing National Cooperative Highway Research Program (NCHRP) research topics.
- Develop training tools to help transfer knowledge from experienced to newer employees within agencies.
- Plan and hold discussions between team members and the AASHTO Committee on Bridges and Structures about AASHTO load and resistance factor design (LRFD) specifications addressing hydrodemolition.

CHAPTER 1

Introduction

Background

Rehabilitation of bridge decks is a recurring task for almost all agencies responsible for maintaining a road network. The task typically entails disturbance of traffic operations, exposure of workers to active traffic, and environmental remediation. Technology, procedures, and practices that can improve agencies' ability to reduce the required time, associated risks, and adverse impacts for deck replacements can have widespread benefits. Several state transportation agencies are finding that hydrodemolition is offering such benefits. Learning and disseminating the lessons of these agencies' experiences can accelerate the adoption of this technology and support the refinement and standardization of its practice, particularly regarding the challenges associated with environmental restrictions, water sources, water disposal, and applications to deeper decks.

A team of state and federal Department of Transportation (DOT) experts, augmented by a subject matter expert on the topic, performed this study (**Figure 1-1**) to and were responsible for:

- Providing specific guidance on details to be studied
- Conducting interviews with the agencies selected to participate in the development of this scan report
- Disseminating the scan's findings on successfully utilizing hydrodemolition on bridge preservation and rehabilitation projects by sharing both successes and lessons learned in planning, designing, specifying, permitting, construction, and performance with all agencies considering using this technology in their bridge preservation strategies.

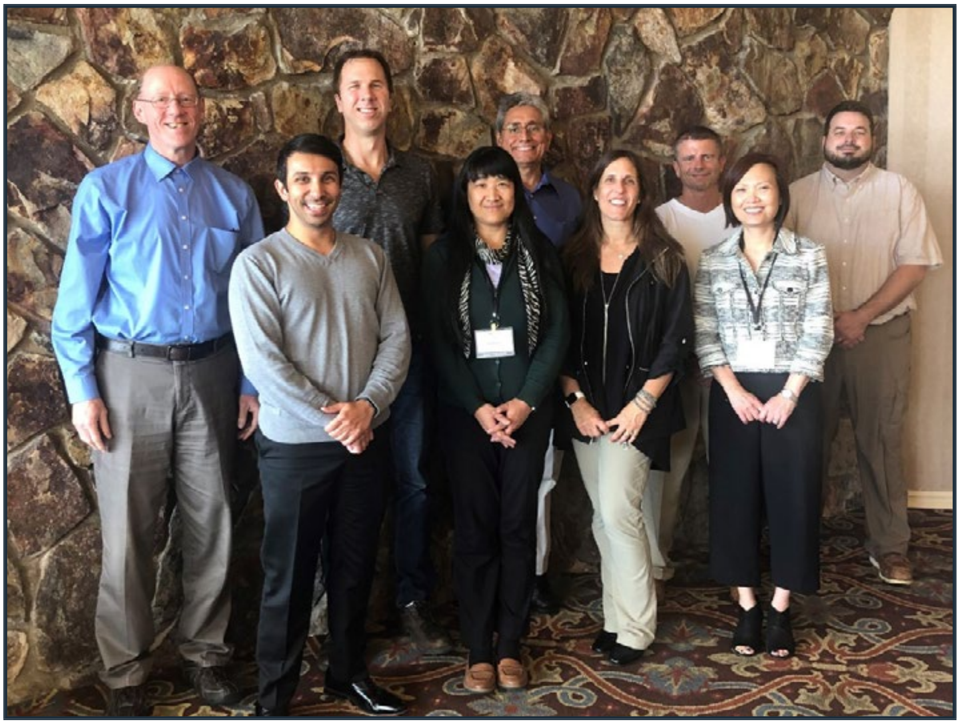

Figure 1-1 National Cooperative Highway Research Program 18-01 scan team

(L to R): DeWayne Wilson, Behrooz Rad, Paul Pilarski, Hannah Cheng, Romeo Garcia, Cheryl Hersh Simmons, Brent Phares, Jenny Fu, and John Belcher

The team makeup was as follows:

- Cheryl Hersh Simmons – Scan Team Chair
  Chief Structural Engineer, Utah DOT
- John Belcher
  Bridge Construction Engineer, Michigan DOT (MDOT)
- Xiaohua "Hannah" Cheng, PhD, PE
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- Zhengzheng "Jenny" Fu, PE
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  Project Manager, District DOT
- DeWayne Wilson PE
  Bridge Asset Manager, Washington State DOT
- Brent Phares, PhD, PE – Subject Matter Expert
  President, Advanced Structural, LLC

The scan team met with users of hydrodemolition and documented their specific applications. To study both the hydrodemolition process and the long-term performance of bridges that have been subject to a partial deck replacement, the team examined not only bridges recently undergoing hydrodemolition, but also bridges that have undergone hydrodemolition deck replacements. The team explored various aspects of the hydrodemolition process, gathering perspectives of agencies and contractors experienced in hydrodemolition. The team specifically focused on how DOTs determined applicable candidates for hydrodemolition, specified construction requirements, and evaluated performance.

The information regarding hydrodemolition for partial depth removal of bridge decks was collected from the agencies invited to participate in this scan (**Figure 1-2**). The scan team engaged structural engineers (including bridge design, construction, and inspection engineers) within the participating states, as well as contractors and equipment suppliers, as deemed appropriate by the presenting state, to study in detail and document the decision-making, processes, and procedures related to hydrodemolition for the preservation and rehabilitation of bridge decks.

The scan's findings provide a better understanding of the current state of the practice for the use of hydrodemolition as a tool for bridge deck preservation. The scan findings also provide DOTs with valuable information on how to develop or improve decision-making related to deck preservation and specifications for construction. This scan was conducted as a peer exchange.

Methodology

The team conducted a desk scan to collect information regarding the state of the practice and the approach of various state DOTs to hydrodemolition. The desk scan included a literature search to identify the best practices and research to date on hydrodemolition. Based on various sources of information, the scan team identified these topics as being essential for advancing the state of the practice for hydrodemolition:

- A decision matrix that leads to the most appropriate action for the bridge deck
- Design criteria and details, construction specifications, and staged-construction approaches utilized on projects specifying hydrodemolition
- Wastewater permitting, control, collection, and reuse or disposal
- Special considerations regarding reinforcement steel location and protection, existing patch materials, other existing or latent field conditions or damage caused by the operation
- Limitations, if any, regarding removal depths
- Preferred materials for the deck itself and/or overlays to replace deteriorated concrete removed during hydrodemolition
- Relative costs for design, construction, maintenance, and inspection of bridges that have been subject to hydrodemolition
- Lessons learned and suggestions for improvement

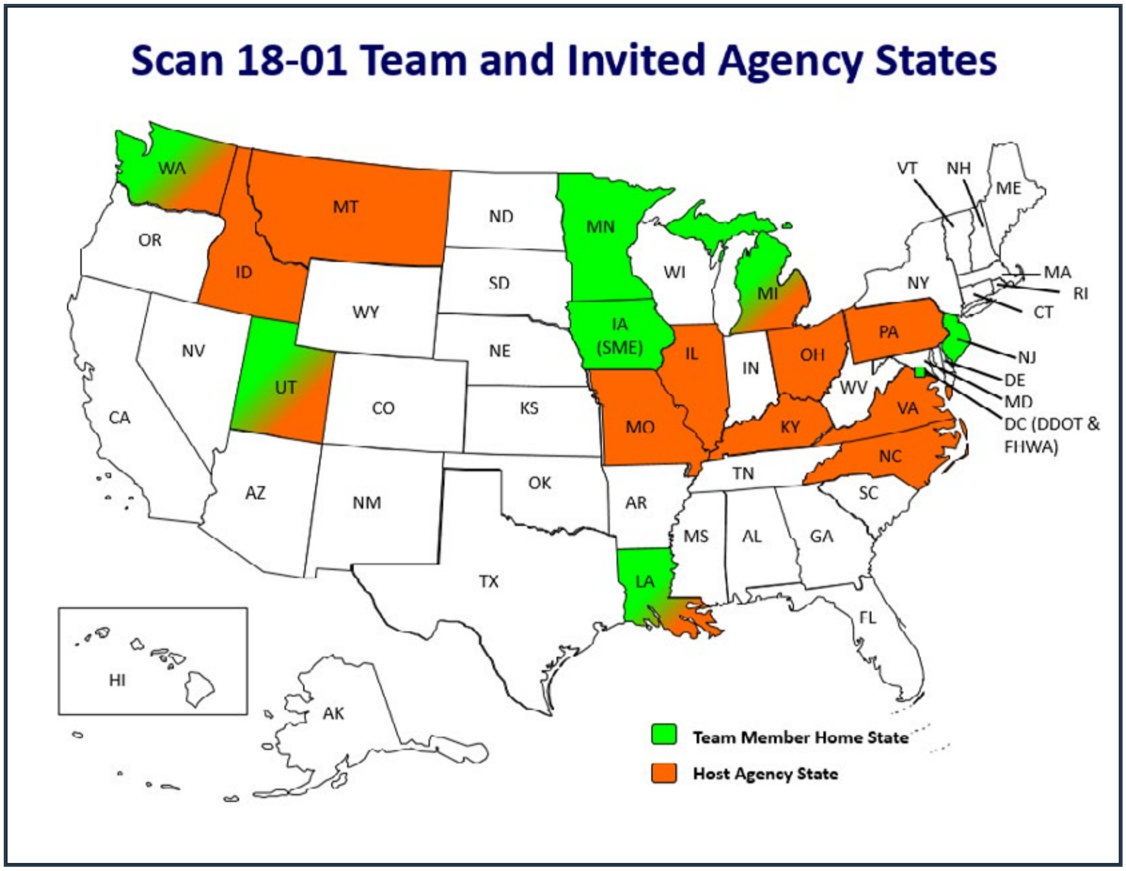

Figure 1-2 States represented in the scan

The scan team conducted a one day meeting in Washington, DC, in November 2018 to review the results of the desk scan, finalize the amplifying questions, and determine the agencies to be studied. As a result of those discussions, the team determined that the agencies to invite to share their experiences included:

- Idaho Transportation Department (ITD)
- Illinois DOT
- Kentucky Transportation Cabinet
- Louisiana DOT and Development (LaDOTD)
- Minnesota DOT
- Missouri DOT
- Montana DOT
- North Carolina DOT
- Ohio DOT
- Pennsylvania DOT (PennDOT)
- Utah DOT
- Virginia DOT
- Washington State DOT

The scan team developed and sent a list of amplifying questions to the invited agencies for their input and suggestions. The scan team and invited DOT representatives met for a four-day workshop in San Diego, CA, the last week of April 2019. Arora and Associates, P.C., developed the workshop program to help facilitate the discussions and technical presentations between the invited speakers and the scan team.

The program provided an opportunity to discuss various aspects of the topics identified during the desk scan. Moreover, other important topics, as deemed appropriate by the team and participants, were addressed during the technical presentations and discussion. At the end of each day of the workshop, the scan team chair provided numerous opportunities for open discussions and for participants to identify the two most important takeaway points from the discussions and presentations. During the fourth day of the workshop, these important takeaway points were compiled under the identified topic areas and presented to the workshop participants, who helped provide consensus and prioritization by voting for the most relevant and important items under each topic.

On Friday May 3rd 2019, the scan team reviewed the findings and provided additional input to help finalize the conclusions and recommendations. The following sections provide information based on those deliberations.

CHAPTER 2

General Information

Introduction

This section presents general information about the bridges under the authority of agencies that participated in the scan. This information includes the number and the deck area of bridges in their inventory, their history of utilizing hydrodemolition technology, and the area of deck removed by this method. The main factors that encouraged agencies to use this method and the roadblocks to its use from the agencies' viewpoint are also provided.

Bridges in Inventory

Among the 11 states that provided information about bridges in their inventory, the average number of bridges is 16,436, with a maximum of 44,814 and a minimum of 4,281. The average deck area of those bridges is approximately 89 million square feet. Seven states provided the amount of deck concrete removed by hydrodemolition, which is an average of 36 million square feet of deck area.

The History of Using the Hydrodemolition Method

According to the collected data, the utilization of the hydrodemolition method goes back to the early 1980s, and it appears that Ohio was one of the method's pioneers. Of the 11 responses, one indicated that hydrodemolition began to be used in the 1980s, five in the 1990s, and the others in 2000 to 2011. Two states provided relatively detailed timelines of their use of hydrodemolition, which are summarized below.

Hydro-Scarification in Illinois

- 1991 – Hydro-scarification allowed as an option, but not required. It is unknown how often it was used.
- 2001 – FHWA performed a bridge deck overlay process review that indicated that hydro-scarification is underutilized.
- 2004 – People still aren't doing it. New memo states that hydro-scarification is required for all overlay projects, regardless of size.
- 2005 – Hydro-scarification of the Dan Ryan Expressway (I-90/94 in Chicago). Contractors did not want to use hydro-scarification; request to mechanically scarify denied. Contractors ended up essentially power washing the bridge deck. Illinois DOT needs to clarify specifications; snarky notes added to specifications:

- "The equipment shall be capable of removing concrete."
- "The equipment shall operate at a minimum of 18,000 psi."

- 2011 – It was determined that mechanical scarification creates a roughened surface that increases the effectiveness of the hydro-scarification. Extensive rewrite of specifications requiring mechanical scarification of the top half inch to create a rougher surface to facilitate hydrodemolition for the rest of the removal. The specification has been stable since 2011.

Hydrodemolition in Ohio

- 1980s – Hydrodemolition was used with mixed results. Eight experimental projects specified hydrodemolition by using plan notes. It was largely used to replace milling. Performance is not feasible because the decks and/or bridges have since been replaced.
- 1990s – A specification committee was formed at the DOT, and the plan note was refined into a specification. Early drawbacks were experienced primarily due to the variable materials removed. Beginning in 1993, the DOT realized benefits on large deck areas in the northeast part of the state.
- 2000s – Hydrodemolition was embedded in the normal working practices. The specification was tweaked and improved to provide consistent scoping. Most bridge overlays are still in place and are performing well.
- 2010s – The specification experienced a significant update after environmental containment became necessary.

The Dominant Features of Hydrodemolition and Roadblocks to Its Use

One important question regarding hydrodemolition is whether the decision to use it is made centrally or regionally. According to the data collected from the 11 agencies, six (Idaho, Illinois, Michigan, North Carolina, Washington State, and Utah) make the decision centrally and one (Pennsylvania) makes it regionally. In Kentucky, the decision is the contractor's choice; the central office rarely specifies hydrodemolition. However, in Louisiana, the decision to use hydrodemolition is made on a project-by-project basis. In Ohio, the 12 districts decide whether to use hydrodemolition and centrally develop and manage specifications; the central office decides for "major" structures. In Minnesota, the decision is made centrally, with the bridge office's regional bridge construction engineer and district bridge maintenance engineer's agreement.

PennDOT provided a decision tree about when to utilize concrete deck overlays (**Figure 2**-1).

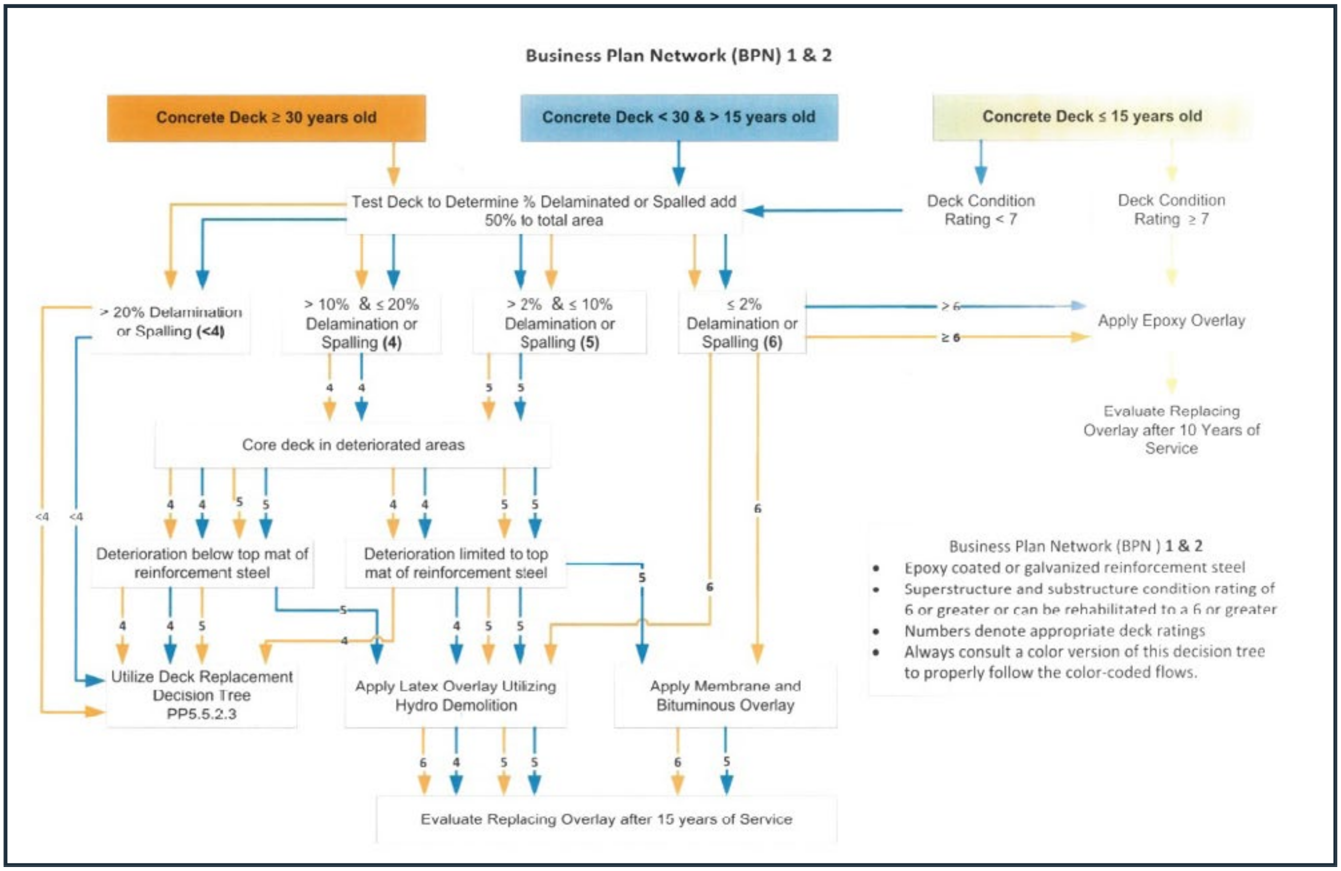

Figure 2-1 Concrete deck overlay decision tree for business plan network 1 and 2 (Pennsylvania DOT)

The agencies were encouraged to start considering hydrodemolition for various reasons. One reason, according to Illinois's response, is that it creates a better profile for the bonding of overlays and patches to existing concrete. Kentucky said that the method provides a more uniform deck removal over jackhammering and does not affect sound concrete when set at a proper pressure setting. In addition, hydrodemolition removes unsound concrete quicker on larger bridges as compared to jackhammers. Louisiana is encouraged to consider this method because of its speed, quality, and uniformity and because it is less invasive, creates less vibration, and is less damaging to remaining concrete and reinforcement. Engineers in Ohio believe that hydrodemolition is efficient, safe, and provides time savings and a good profile. Like some other states, Minnesota responded that the overall cost of the hydrodemolition method is lower compared to jackhammers and that also it provides better surface preparation for a modified concrete overlay.

Michigan believes that hydrodemolition is just generally better than rotomilling and using jackhammers and is specifically better on deteriorated decks. Most states proficient in using hydrodemolition have found that milling results in microcracking that damages the concrete that is ultimately left in place; these microcracks are not found when hydrodemolition is utilized.

In North Carolina, hydrodemolition is considered a programmatic approach to bridge preservation that provides controlled and selective removal to a prescribed depth (i.e., removes unsound and chloride-containing concrete) and provides a good bond for various overlay types. North Carolina also believes that, from an economic perspective, the overall cost is lower compared to other removal methods. The resulting high-quality overlays result in bridge resurfacing without bridge replacement, which results in saving millions of dollars.

In short, the states participating in the scan believe that this method is cost effective when combined with an appropriate overlay material, thereby resulting in a durable solution.

Eight agencies participating in the scan provided their viewpoint about roadblocks to the use of hydrodemolition. Pennsylvania and Washington State mentioned that there is no major obstruction to using this method, that it is standard practice, that its use is widespread based on cost and deck condition, and that specifications are regularly updated to keep up with current practice.

In Kentucky, the costs of mobilization and the availability of capable contractors are some of the roadblocks. Louisiana believes that lack of knowledge, training, standard practices guidance, contract enforcement, noise issues, and environmental concerns are the main roadblocks to using hydrodemolition. The unknown durability benefit for life-cycle cost and limited budgets are obstacles in Minnesota. Ohio responded that the roadblocks to using hydrodemolition are environmental concerns, adjacent box beams, and post-tensioned ducts near the surface. Utah's response was that doing hydrodemolition over railroads and live traffic were concerns and challenges, as were water availability and environmental issues. In Virginia, traffic-control restrictions and the agency's bridge culture are two of the roadblocks to the use of this method.

Scoping and Planning

Introduction

This section presents factors that affect the scoping and planning of hydrodemolition projects. These factors are categorized in three groups: application, decision making, and environmental issues.

Application

The hydrodemolition method can be utilized for applications other than partial bridge deck removal. In Louisiana it is also used for full-depth deck removal, structure widening, superstructure repair, and joint replacement. The pay item in Louisiana is removal of bridge deck, and it is commonly paid on a per-square-foot or per-square-inch basis. In Kentucky and Utah, hydrodemolition is also used for expansion joint replacement. Michigan uses this method for expansion joints, for projects involving removing damaged steel girders and removing the concrete deck around the girders. In Minnesota, a contractor proposed deck removal over "historic prestressed beans" to prevent damage to the beams during full deck replacement.

In Ohio, the hydrodemolition method is allowed for vertical applications (such as for parapets or substructures); however, shielding is a challenge in these projects. This state specifically dictates that hydrodemolition is not to be used if the delamination level exceeds 70% of the deck area.

Pennsylvania reported that there have been a few cases of removal of unsound or poor-quality concrete on piers, retaining walls, and in tunnel rehabilitation. In some states hydrodemolition is allowed for slope walls; however, this option is generally not chosen. In Illinois, this method is allowed on walls and substructure units, but it is unknown how often this is used. Illinois also allows its use for slope walls; however, this option is generally not chosen. In North Carolina, there is no vertical application, and partial depth hydrodemolition is used for tying to existing rebar for construction of new bridge barriers.

One of the items which is considered in this study is the applicability of the hydrodemolition method for different kinds of structural systems. In most cases there are no restrictions on structure type, and this method is generally allowed for most kinds of structural systems, such as decks on girder, post-tensioned box beams (with care), T-beams, and deck bulb-T girder. However, this method is not allowed for concrete-filled steel grid decks, girders with a structural deck, post-tensioned bridge decks, or structures with excessive vibrations and deflections. Hydrodemolition should be cautiously used on voided slabs, adjacent prestressed box beams, and on older bridge decks. Furthermore, this method is not suggested for box girders and post-tensioned (PT) top flanges due to redistribution of stress and the uncertainty with loss of negative moment stress redistribution with unknown top deck patching geometry.

In some states there is a concern with using hydrodemolition to remove unsound concrete on filled steel grid decks. The concern involves the removal of concrete in the small "pockets" of the grid. Also, in some cases, hydrodemolition may need to be used sequentially for removal on integral bridge decks.

Decision Making

One of the issues in deciding to use the hydrodemolition method is determining how and when it can be a proper choice. Various strategies are cited about this issue. In Idaho, if the deck delamination is up to 25% to 30% and if the desired design life is about 25 years, then the hydrodemolition method is used. Some states do not have a specific policy about it or make it the contractor's responsibility to select the most appropriate method. The general rule in Illinois is that if the area of patching exceeds 15% of the bridge deck area, hydrodemolition is utilized.

In Louisiana, there is no systematic approach, and bridges are identified based on inspection findings, district input, and field observations. In this state, the hydrodemolition method typically is used as part of a preventive maintenance strategy (i.e., the bridge is otherwise in good condition).

Michigan developed a matrix that defines limits on the top and bottom of the deck. Pennsylvania's policy is to consider three variables: deck condition, cost of preservation using hydrodemolition versus full deck replacement, and traffic volumes/duration of work as it affects the traveling public. In Virginia, if the total deck area is in condition states 2 to 4, the hydrodemolition method is utilized. A hierarchy list of treatment alternatives guides engineers to make the decision collaboratively with central and district engineers.

One of the beneficial tools that can result in systematic decision making about bridge deck rehabilitation is a deck preservation matrix, which includes decision making for hydrodemolition. According to the collected data results, six states out of 10 (Louisiana, Michigan, Pennsylvania, Utah, Virginia, and Ohio) have a preservation matrix and use it in their decision-making procedure. Figure 3 1 shows a typical preservation matrix, which was provided by Louisiana. Kentucky does not have a matrix, and North Carolina has one under development. Minnesota is still evaluating where the economy is best served, since traditional milling combined with low-slump overlays has been giving more than 30-year service-life extensions under high traffic.

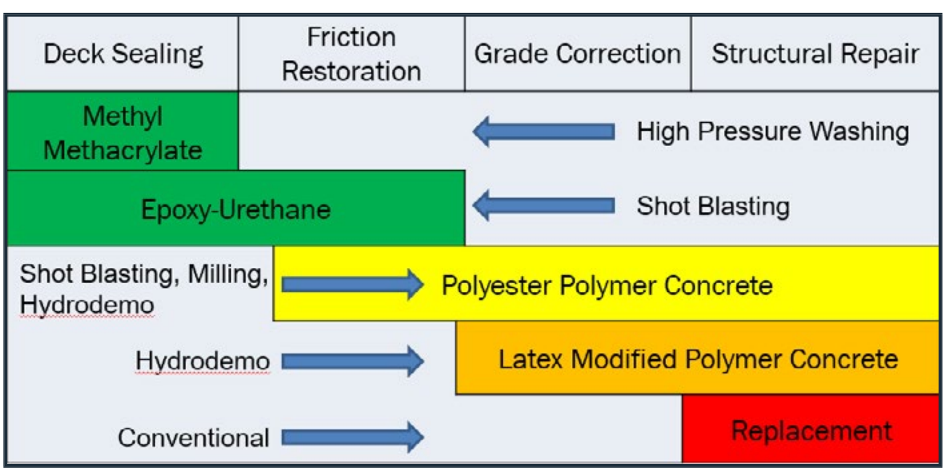

Figure 3-1 Deck preservation matrix (Louisiana DOTD)

Decision making needs good information about the condition of the deck. The states that participated in the scan were asked about what testing/evaluation of the bridge deck is needed prior to decision making and/or plan development. Agencies have a variety of testing and evaluation methods. Idaho uses ground penetrating radar (GPR), thermal, acoustic measurement, and chloride testing methods. Once the decision is made, the condition data are corroborated and used to calibrate the removal equipment. In Illinois, two 30-foot-square sections are tested (one in an area of sound concrete and the other in an area of unsound concrete), and the gathered data are used. If equipment does not appear to be reliably removing concrete (i.e., removing too much or too little), a third test section is performed on an area of sound concrete.

In Louisiana, National Bridge Inventory (NBI) inspection data and visual assessment was a common evaluation method. In future applications, Louisiana plans to require deck coring and nondestructive testing (NDT). Louisiana recently executed an indefinite delivery/indefinite quantity contract with a nondestructive testing (NDT) consultant to assess the condition of decks on viaduct structures using a combination of visual, acoustic, and thermal assessments.

In Minnesota, the evaluation procedure includes underside visual assessment and strategic sounding of the deck underside. The evaluation method in Ohio to determine the condition is based on the annual inspection's results, which can include hammer sounding, chain dragging, coring, ground-penetrating radar, infrared, impact echo, chloride concentration testing, half-cell, and bond strength testing (using two or three methods to correlate). In Pennsylvania, however, and on most projects, the decision is based simply on the visual inspection of the deck. Design inspections, deck soundings, and the condition of the underside of the deck are evaluated. Also, there are instances where cores are taken to obtain a chloride profile to provide data to help make the decision regarding depth of removal.

Utah's evaluation methods include sounding, visual, ground-penetrating radar, testing of chloride content (15 pounds per cubic foot), and Schmidt rebound hammer. Washington State has a matrix for evaluation, and in some others it is the contractor's responsibility. In Washington State, inspection data is used to identify initial deck rehab candidates (patching > 2%) in two steps. First, the bridge deck soffit condition and inspection comments are reviewed, and then the bridge deck details are reviewed to evaluate the risks of deck rehabilitation versus deck replacement.

Environmental Issues

Wastewater and Debris

Hydrodemolition uses high-pressure water to remove the concrete. As a result, managing and treating the resulting wastewater are important considerations. One issue is how to dispose of the treatment water, and states use various strategies. In Idaho, the wastewater becomes the contractor's property and is disposed of by land application off site. Using rock checks in the gutter to strain the runoff is a method Kentucky uses; rocks checks are typically 6 inches tall, and 1 linear foot wide. Louisiana utilizes both on-site treatment and off-site disposal. In North Carolina, there are three ways to dispose of the water:

- Slurry: to permitted wastewater treatment plant or programmatic land application
- Separated liquids: to wastewater treatment plant
- Solids: to permitted landfills, programmatic land application, and permitted beneficial reuse as soil fortification or structural fill

Other methods of addressing wastewater issues are used in Ohio, including land application (requires work on the front end; not used commonly), wastewater recycling plant (also not used commonly), and utilizing a National Pollutant Discharge Elimination System-permitted facility (more common). The strategies in Utah are using a treatment facility or designated manholes, building a contractor's own treatment facilities, and evaporation ponds. Minnesota has two options: on right of way (ROW) (filtered water on ROW in area of bridge) and off ROW (approved disposal area which are both on- and off-ROW areas that meet the same requirements). In Pennsylvania, approved waste sites are determined for this issue. In Virginia, wastewater is disposed in ROW sight.

The wastewater that results from hydrodemolition can be treated and reused; however, reuse is uncommon. States use various methods and performance metrics for water treatment. Illinois does not require treatment of wastewater; however, the contractor is responsible for disposing of it in a method conforming to applicable laws. The treatment method in Louisiana includes pH reduction ($6.0 \leq pH \leq 9.0$) and sediment removal (total suspended solids (TSS) ≤ 90 mg/L). This procedure requires that there be no discharge of floating solids or visible foam in other than trace amounts, and the wastewater must be free of oil and other oil materials and free of toxic materials in quantities that could cause acute toxicity to aquatic organisms. Furthermore, it states that there shall be no visible sheen or stains attributable to this discharge. In North Carolina, wastewater with a $pH > 12.5$ is considered hazardous material and requires a hazardous materials plan. In Pennsylvania, the prime contractor installs erosion and sediment (E&S) controls at inlets and scuppers prior to hydrodemolition. In Utah, pH and total suspended solids (TSS) are controlled, and in Idaho wastewater is disposed by land application off site.

Utah requires the contractor to recycle or reuse the wastewater; however, most of the agencies, including Idaho, Michigan, Minnesota, and Virginia, do not require contractors to recycle or reuse wastewater. In Illinois, the contractor is required to control the runoff water generated by the various construction activities in such a manner as to minimize, to the maximum extent practicable, the discharge of untreated effluent into adjacent waters, and shall properly dispose of the solids generated according to specific protocols. The contractor also needs to submit a water management plan to the engineer, specifying the control measures to be used. The control measures shall be in place prior to the start of activities that will generate runoff water. Runoff water shall not be allowed to constitute a hazard to adjacent or underlying roadways, waterways, drainage areas, or railroads, nor will it be allowed to erode existing slopes.

Some states have some requirements for both debris and water (on bridge/under bridge). Idaho takes these steps to contain the wastewater:

- Temporarily plug bridge drains to prevent materials from entering the drainage system.
- Collect runoff water and residual material within existing roadway slopes.
- Line temporary collection ponds with a separation geotextile.
- Do not allow runoff water or residual material to flow into vehicular or pedestrian traffic areas or nearby waterways.
- Provide shielding to ensure containment of dislodged material within the removal area
- Protect the public from flying debris on and under the project site

In Illinois, vacuum trucks are the most common method of removing water; the water is removed as it is being used. In Kentucky, all drains are blocked for on-bridge cases and, for under-bridge cases, debris and water are captured before they get under the bridge. According to the collected information, in Ohio, discharge to the water is prohibited, and the contractor must provide a sludge management plan. In Utah, hydrodemolition needs water containment and a management plan that depends upon deck condition and contractor capability.

For hydrodemolition projects, states such as Michigan sometimes use a memorandum of understanding or other agreement with appropriate state environmental agencies and statewide permits to control environmental pollution. However, Minnesota does not use such an agreement. According to collected data results, Idaho permit requirements are assessed on a case-by-case basis. In Louisiana, statewide bridge construction and maintenance activities need a Pollutant Discharge Elimination System permit. In Ohio, a general permit is needed, and any land application requires that plans be sealed by a professional engineer. In Pennsylvania, the hydrodemolition contractor is responsible for disposing of vacuumed material at an appropriate waste site. The prime contractor may install erosion and sediment controls at inlets and scuppers prior to the hydrodemolition; separate permits are not typically required for this condition. Utah has a three- to six-month turnaround time for permits, and they must be obtained early and often. A permit is required in North Carolina, and industrial requirements for wastewater containment, treatment, and disposal by the Department of Environmental Quality must be considered.

Noise

One additional environmental concern of hydrodemolition projects is noise pollution. Some states (e.g., Illinois) have no restrictions, while others (e.g., Ohio) may identify specific allowable noise levels for the work in plan notes. In Minnesota, equipment should be utilized that operates at a noise level < 90 adjusted decibels, as measured from a distance of 50 feet. The restriction for Pennsylvania is that when the project is close to sensitive areas, work may be required to be performed only during certain hours. Although it is rare that noise monitoring or provisions due to the hydrodemolition process are included, Louisiana does have specific requirements, including:

- The equipment must operate at a noise level of < 90 decibels at a distance of 50 feet.
- Compliance with local noise ordinances (though many contain exceptions for highway construction activities)

Maintenance of Traffic

One of the issues in hydrodemolition projects is maintenance of traffic (MOT) constraints/ limitations during depth deck removal and the effect of construction duration on the MOT plan (e.g., no hydrodemolition over live traffic and phasing). In Louisiana, ground areas and facilities below the structure are protected from damage by debris during hydrodemolition and removal operations, and vehicular, pedestrian, and marine traffic are rerouted or restricted from areas below hydrodemolition operations. In Minnesota, the underside deck condition of bridges over traffic must be verified by the contractor by sounding prior to milling. There is no restriction over traffic if the bridge deck is deemed to be sound. In Pennsylvania, the volume of traffic is a key decision in using hydrodemolition versus a full deck replacement. Utah's constraints over routes with high average daily traffic may render the cost of hydrodemolition over live traffic uneconomical. Virginia's strategies reflect that MOT constraints/limitations have extensive influence; operations should be at night and bridges should be bundled together.

CHAPTER 4

Design

Introduction

This section provides more detailed information about the various steps in designing a hydrodemolition project: estimate development, specification, and plan.

Estimate Development

The bridge deck is a structural member that distributes the loads among other load-carrying members. During hydrodemolition projects and post-construction, sometimes it is necessary to estimate and evaluate the bridge deck's structural capacity. In Louisiana, for latex-modified concrete (LMC) deck overlay projects, no structural capacity evaluation is typically needed since only 1½ inches of the deck is removed while the lane is closed and replaced with the same thickness of LMC and no additional weight is added to the structure after construction. However, for other structural component removal, a structural capacity evaluation may be required depending upon the limits of removal.

In North Carolina, the structural capacity evaluation depends on project-specific requirements/situations (e.g., the amount of removal and the construction equipment.). In Pennsylvania, research showed that with hydrodemolition and latex overlay, the system is considered to act compositely with the underlying deck. In Washington State, the state bridge office assigns designers to evaluate particular types of bridges that will have a deck rehabilitation, as well as bridges with integral decks (like a concrete box) that take more effort. In Kentucky, trailers with the hydrodemolition air compressor, for example, are not allowed to be parked on the bridge if it has a posted weight limit. However, in some states, like Ohio, the evaluation of the deck capacity for the hydrodemolition operation is not considered or spelled out in specifications or in the bridge design manual. The reason is that the initial design includes provision for future overlay, and adding less than 10 pounds per square foot does not trigger a new load rating. In some states, like Idaho and Minnesota, this issue is not a concern; no special accommodation is made, and it is treated as original construction.

One of the notable issues in hydrodemolition projects is cost estimation, and states have various procedures for evaluating cost. In North Carolina, preliminary estimating takes place by considering \$35 to \$40 per square foot for hydrodemolition, LMC, and traffic control. The final estimate is based on estimated plan quantities, including:

- Scarification (square yard)
- Hydrodemolition (square yard)
- Class II (square yard)
- Class III (3.5 to 4 times the cost of Class II; square yard)
- Concrete for deck repair (cubic foot)
- Placing and finishing LMC (square yard)
- LMC (cubic yard)

Payment is based on plan quantities, except materials.

In Idaho, the maximum removal amount, minimum overlay, and aggregate diameter are used to estimate cost. In Illinois, estimation for overlays are typically $80 to$120 per square yard. Typical costs of hydrodemolition in this state for three-quarter-inch removal is $45 per square yard and for two to three inches of removal is $80 per square yard. Cost information for the total project in Virginia is around $60 per square foot. In Washington State, previous contracts are reviewed with consideration for the condition of the bridge. In Kentucky, the cost-estimation procedure is incidental to partial-depth patching.

In Pennsylvania, projects are bid with a constant depth removal based on 1¼ inch removal. The deep removal is considered a variable item and is paid based on latex truck batch meters at point of placement. Cost history on similar projects with similar condition is considered. Four or five items generally are evaluated:

- Scarification square yard (SY) (sometimes standard [¼ inch depth] sometimes special provision [any depth other than ¼ inch])
- Hydrodemolition SY (special provision)
- LMC overlay SY (standard item)
- Variable depth cubic yard (CY) (special provision).

Ohio has a table (**Figure 4-1**) that helps designers estimate costs.

18. WHAT IS YOUR PROCEDURE FOR ESTIMATION OF COST PROCESS?

	848	Square yard (square meter)	Micro-silica Modified Concrete Overlay using hydro-demolition [___ inch (mm)] thick
	848	Square yard (square meter)	Latex Modified Concrete Overlay using hydro-demolition [___ inch (mm)] thick
	848	Square yard (square meter)	Superplasticized Dense Concrete Overlay using hydro-demolition [___ inch (mm)] thick
	848	Square yard (square meter)	Surface preparation using hydro-demolition
Variable	848	Cubic yard (cubic meter)	Micro-silica Modified Concrete Overlay (variable thickness), material only
	848	Cubic yard (cubic meter)	Latex Modified Concrete Overlay (variable thickness), material only
	848	Cubic yard (cubic meter)	Superplasticized Dense Concrete Overlay (variable thickness), material only
	848	Lump sum	Test slab
	848	Cubic yard (cubic meter)	Full-depth repair
	848	Square yard (square meter)	Wearing course removed, asphalt
	848	Square yard (square meter)	Existing concrete overlay removed ______ nominal thickness
	848	Square yard (square meter)	Hand Chipping
	848	Square yard (square meter)	Removal debonded or deteriorated existing variable thickness concrete overlay

Figure 4-1 "What is your procedure for estimation of cost process?" (Ohio DOT)

Specification

Exposure of Reinforcing Steel

In hydrodemolition projects some states have a specification for the exposure of reinforcing steel. In Illinois, for decks not in good condition, reinforcement is often required to be exposed. Kentucky, however, has no requirement as long as the concrete is sound beneath the reinforcing bar. Louisiana, too, has no requirement to expose reinforcement; however, 1½ inch removal will typically expose the top surface of some reinforcement. According to information from Ohio, once half of the bar is exposed, additional removal below the bar is required; however, it avoids rehabilitation levels that expose bars in negative moment areas. Pennsylvania is moving away from requiring the reinforcement to be exposed. For this purpose, the pressure of the hydrodemolition equipment is set based on test patches. Providing clearance around the rebar is required when the adjacent concrete is rust-stained or debonded. Utah has specifications that require all top bars to be exposed.

Milling Prior to Hydrodemolition

Another requirement that state agencies may have is that milling be performed before starting the hydrodemolition operation. In most of the states milling is allowed and is actually preferred. In Illinois, typically milling is used to remove all concrete except the last half inch. In Kentucky and Ohio, for decks without existing overlay, one quarter inch milling will be considered and, for decks with existing overlay, the whole existing overlay is allowed to be milled in advance. Louisiana's requirements allow milling up to half an inch for initial deck removal, and it can exceed half an inch if the reinforcing steel's depth can be accurately identified. In Washington State, 1 inch of an existing modified concrete overlay is allowed to be removed with a rotomill. In Utah, milling is conducted for maximum removal of 1 inch, and now it is required on all projects. In North Carolina, milling is allowed to within half an inch of the required hydrodemolition depth, and Virginia allows it up to the half inch above the rebar. In Michigan, initial milling is allowed, and its depth varies between three-quarters of an inch to 1 inch. In Minnesota, bridges to date have already had a low slump overlay where they are considered for this investment; most of these would have a 1 inch cover to the reinforcement from the bottom of the existing overlay; milling is to fully remove the concrete overlay. Idaho does not allow initial milling in concrete.

Scoping and Planning

One of the aspects that needs to be considered in hydrodemolition is the depth of concrete removal for the bridge deck and determination of the estimated depth. According to information from several state DOTs, there are various approaches to develop these estimates. In Illinois, the plans typically specify three-quarter-inch removal for overlays. Also, once a bar is more than 50% exposed, it may be required to be undercut by 1 inch to ensure that there are no voids around the bar when the new concrete is placed. In Kentucky, one quarter inchof the original deck may be removed. In Louisiana, the depth of concrete removal is based on the required thickness of the overlay, which is typically between 1½ and 2 inches (i.e., to maintain the existing grade).

In Idaho, the depth of the removal is a function of aggregate size, clear cover to reinforcement, and deck thickness; there is a process for estimating the depth. For example, Idaho uses the procedure shown in **t** to determine the new deck thickness.

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CONCRETE OVERLAY DETAILS

DECKS WITH LESS THAN 2½" COVER ON THE TOP LAYER OF REINFORCEMENT

The new concrete overlay shall provide 2½" of cover for the top layer of reinforcement and shall have a minimum thickness of 1.5".

The new deck thickness is determined by subtracting the existing top rebar cover from 2.5" and adding the result to the thickness of the existing deck.

REMOVAL DEPTH

C_e = existing cover
T_e = existing deck thickness
D_m = mean removal depth
S = ½ the maximum aggregate size

ITD Construction Specifications	Maximum Aggregate Size
Up to 1967	2"
Between 1967 & 1976	1.5"
1976 & after	1"

T_n = new deck thickness = $T_e + (2.5 - C_e)$

$Te - (D_m - S) = Tn - 1.5 \equiv D_m = S + C_e - 1.0$

On the contract plan details, show D_m , S, C_e, T_e, & T_n values.

CONCRETE OVERLAY QUANTITY

Use D_{max} to calculate the concrete overlay quantity. This will provide a pay item cost that should reduce cost over-runs during construction.

$D_{min} = D_m - S$
$D_{max} = D_m + S$

EXAMPLE

$T_e = 6"$
$C_e = 1.25"$
$T_n = 6 + (2.5\text{-}1.25) = 7.25"$
1957 ITD Construction Specifications = 2" max aggregate
$S = 2"/2 = 1"$
$D_m = T_e - T_n + 1.5 + S = 6 - 7.25 + 1.5 + 1 = 1.25"$

$D_{min} = D_m - S = 1.25 - 1 = 0.25"$
$D_{max} = D_m + S = 1.25 + 1 = 2.25"$

Concrete overlay quantity
Deck Thickness after Removal $T_r = T_e - D_{max} = 6 - 2.25 = 3.75"$
Overlay thickness = $T_n - T_r = 7.25 - 3.75 = 3.5"$

Figure 4-2 "Procedure for determining new deck thickness (Idaho Transportation Department)

For shallow decks, Michigan requires three-quarters of an inch removal; for deep decks, for estimating purposes to the top mat of rebar is considered the minimum removal. Minnesota requires one half inch of removal from the scarified surface to the top of the removal. In North Carolina, prior to hydrodemolition, milling or scarifying to within one half inch of the total removal depth takes place, which removes most of delamination and spalling. Then, using hydrodemolition, 1¼-inch minimum LMC placement thickness is removed (typically removing what is going to be put back, one to one). In this procedure the existing plans are reviewed and field measurements are taken. In Ohio, the depth of concrete is removed to1 inch from the mortar line; the top mat of the steel is not allowed to be exposed. However, there is allowance for one quarter inch of milling per specification (this can be modified with plans).

According to Pennsylvania, visual inspection results, deck soundings, condition of the underside of the deck, and chloride content in cores may allow for depths deeper than the planned overlay. These data aid in determining how deep to scarify prior to hydrodemolition. Generally, 5% to 10% of unsound areas are quantified for full-depth repairs to be performed after hydrodemolition but before overlay. This is principally used to provide a pay item in the contract in the event full-depth repairs are necessary. Typically, 1 inch is removed by milling/scarifying, with one quarter inch removed with hydrodemolition for sound concrete. This provides a depth of 1¼ inches (peaks of hydrodemolition to top elevation), resulting in the minimum thickness required for LMC overlay. Extra depth for areas below peaks and due to deeper unsound areas are paid separately as variable depth (cubic yard). LMC trucks are calibrated and metered so the additional quantity can be calculated after placement. In Utah, the depth of concrete removal goes below the top mat. However, in Washington State, the depth of the concrete removal varies from one half inch to 3 inches; when removing an old concrete overlay, the concrete is removed to the top mat of rebar.

After removing the concrete with hydrodemolition, different kinds of materials can be used as replacement for the removed concrete. The common materials are LMC and microsilica concrete overlays. All states participating in this scan noted that selecting the proper material depends on the depth of the concrete removal. For example, for relatively thin removals in Louisiana, latex modified polymer concrete overlay, polyester concrete overlay, and high-density concrete overlay were options to substitute the previous layer. However, for deeper removals, rapid-set polyester polymer concrete or grout and standard "Class A" polyester polymer concrete mix were utilized. One agency uses LMC with seven-day strength gain or very early strength LMC with three-hour strength gain for overlays. For patching full-depth removal areas, either a 4,500-pounds per square inch (psi) concrete mix or a fast-set repair material is allowed.

Minnesota requires that, for prefill patches deeper than 4 inches, a contractor-designed deck mix to 1 inch above the reinforcement (bottom of future concrete overlay) be used. After placement, the mix is wet cured for 72 hours, and then a low-slump wearing course or microsilica mix with fibers wearing course is placed.

In Ohio, three main materials, including LMC, microsilica, and modified and superplasticized dense concrete (SDC) are used, depending on the concrete removal depth. The range of thickness of material in Ohio is as follows:

- LMC overlay is 1¼ to 2½ inches (4 inch spot maximum)
- Microsilica modified concrete overlay is 1½ to 3 inches
- Superplasticized dense concrete overlay is 1¾ inch or greater

More detailed information about the overlay material in Ohio is provided in **Table 4-1**.

ODOT Bridge Deck Overlay Guide

Type	Specification	Lifespan (years)	Cost (S/SF)	Typical condition state rangers				thickness (spot max)	Commentary
				CS 2	CS 3	CS 4	Deck Summary		
Sealing (HMWM)	705.15	5 to 7	15-17	≤5%	≤1%	≤0%	≤7	N/A	- Should not be placed on concrete or cementitous patch material less than 28 days old - Seals cracks - quick operation (1-day) - Very inexpensive aggregate (mason sand) - Not reliant on preparation. - Does not provide wearing surface - Can be aesthetically displeasing (green tint) - Use on New Decks that have extensive cracks. recommended sealer is applied 6 months after construction of new concrete deck or overlay.
Epoxy Polymer Overlay	SS 858	10 to 15		≤10%	≤1%	≤0%	≤6	0.375" (2")	- Seals cracks - Typically 1 to 3-day operation - Extremely sensitive to surface preparation - Susceptible to snow plows - Provides aesthetic wearing surface - Increases skid resistance - Dark aggregate retains more heat reducing icing of the bridge - Cannot be placed on concrete or cementitious patch material less than 28 days old. - No grade correction with overlay * Use on New Decks that have extensive cracks whether or not the cracks have been sealed with HMWM
Polyester Polymer Concrete (PPC)	Plan Note							1.0 to 1.5 (12")	- Very Rapid Curing Overlays Less than 24 hours, night closure - Require mobile mixers - good for remote locations and fast application - Max depth of 12" however not economical
Latex Modified Concrete (LMC)	SS 953 (latex modification used with SS847 or SS848	20 to 30	75-85					1.25 to 2.5 (4")	- Best suited for second-generation overlay. LMC overlay are difficult to remove from the original concrete deck, overlay may take multiple passes of the hydrodemolition equipment. Excessive removal and some "blow-through" may be expected - Add Type III cement - Fast Curing Overlays - Weekend closure - Very susceptible to plastic shrinkage cracking - Requires mobile batcher mixer - Typically has higher flexural strengths than plain concrete - Very low chloride permeability - Can be used with a high early strength for weekend overlays
Micro-silica Modified Concrete (MSC)	SS 847 or SS848	20 to 30	55-76	≤ 25%	≤ 15%	≤ 5%	≤ 5	1.5" to 3.0" (should not exceed 4")	- Fast Curing Overlays - Weekend closure - Micro-silica is very cohesive and behaves somewhat differently than conventional concrete (very sticky) and needs water reducer, slump needs to be at max allowable to achieve same workability
Superplasti-cized Dense Concrete (SDC)	SS 847 or SS848	20 to 30	60-85	≤ 25%	≤ 15%	≤ 5%	≤ 5	1.75" in and greater	- Used on typical overlay projects
Asphalt Concrete Overlay (special)	SS 856	10 to 12 Yes		≤ 20%	≤5%	≤ 1%	≤ 6%	3" to 4"	- Proprietary item - name brand Rosphalt - Installed at typical asphalt rates - Asphalt with Mix Modifier (not polymer)
Asphalt Concrete Overlay with waterproofing membrane		10 to 12 Yrs		≤ 25%	≤ 15%	≤ 5%	≤ 5	3" to 4"	- Leave membrane in place thru one milling of asphalt, replace membrane on subsequent milling project. - Can be used as second generation deck treatment or when joints need to be replaced - Can be used on New Decks that have extensive cracks whether or not the cracks have been sealed with HMWM. - Not ideal for horizontally curved bridges. - Not for use on bridges that exceed 4.5% superelevation - Cost of deck repairs not included

Existing concrete overlay removed with scarification add.........$35 Sq/Ft (2019)
Existing concrete overlay removed with scarification with Hydrodemolition prep add ....$55 Sq/Ft
Note hand chipping is an additional cost add ....$60 Sq/Ft.

Table 4-1 Overlay material: Ohio

In Pennsylvania, both conventional LMC and rapid-set latex are utilized. The choice to use rapid-set latex is based on traffic volumes. In Washington State, modified concrete overlay or a concrete Type 2 mix is used, and no fast-curing patching materials are allowed.

Illinois typically uses LMC and microsilica concrete overlays. Typical decks in Illinois have 2¼ inches of top clearance, so a three-quarter-inch removal on a deck in good condition will not expose reinforcement. Following are the most common materials that are used in Illinois, with their minimum thickness:

- Epoxy overlay: an epoxy urethane resin with a fine aggregate wearing surface (epoxy overlay) with a minimum depth of three-eighths of an inch
- Membrane waterproofing with bituminous overlay: membrane waterproofing system installed on a bridge deck covered with a bituminous wearing surface with a minimum thickness of 2½ inches.
- LMC with a minimum depth of 1¼ inch

In hydrodemolition projects it is possible for state agencies to use a standard specification or to have a special provision. The collected data indicated that most of the states (i.e., Idaho, Louisiana, Michigan, Ohio, Virginia, and Washington State) use a standard specification. Pennsylvania currently uses special provisions for hydrodemolition while it is updating its standard specifications to include hydrodemolition. North Carolina and Minnesota are using a special provision.

When hydrodemolition has been specified, agency policy can be different when it comes to allowing other removal processes as part of a value engineering (VE) proposal. Some states (e.g., Kentucky, Minnesota, Virginia, and Washington State) do not allow it. In Illinois, VE proposals to avoid doing hydro scarification are not approved; the state typically doesn't typically see VE proposals for this type of work. However, in Louisiana, there were cases where hydrodemolition was specified in the plan, but the contractor preferred other methods. The construction section has allowed it even with the engineer of record's objection, indicating that quality was at risk in some cases. Also, noise was another reason for using alternative methods to hydrodemolition in sensitive areas (e.g., hospitals, hotels, or residential neighborhoods).

Pennsylvania evaluates the proposal; however, the proposed VE savings to the department would have to be greater than 50% of the bid cost for the new deck. Essentially the savings would have to cover the future costs of removing and replacing the overlay.

Plan

One item of interest in hydrodemolition projects is related to whether agencies provide any test/condition data, either with bid documents or in another manner. Kentucky provides it if it is requested during the bidding process. Louisiana, however, does not provide any test data. In Minnesota, any chaining data may be provided through reference information documents. Bridge inspection reports are available upon request in Washington State. In Pennsylvania, test/condition data are not typically provided at bid time, however a pre-condition assessment is required prior to scarification.

Public safety during hydrodemolition operations (e.g., lane closures below and false decking) is a significant issue. Illinois allows traffic to be present under hydro-scarification operations and uses timber protective shielding to prevent concrete from falling on traffic. In Washington State, depending on the type of bridge and the condition of the deck, and in states like Kentucky, Michigan, Minnesota, and Virginia, lane closure (sometimes during the night) or full closure around the work area and the use of false decking may be required. Pennsylvania specifies that shielding be provided, as required, to ensure containment of all dislodged concrete within the removal area to protect property and the traveling public from flying debris on, adjacent to, and below the work site. Hydrodemolition equipment is built with shielding. However, in Louisiana, it is contractor's responsibility to submit proposed methods to shield the work area and prevent debris from entering travel lanes, and/or other areas that are not to be disturbed.

This scan also considered limitations on time of year and temperatures. In states like Idaho, Kentucky, Louisiana, Ohio, North Carolina, Michigan, and Washington State, there were no seasonal or temperature limitations for the hydrodemolition process itself; however, there were some limitations for the replacement overlay material. For example, in North Carolina, LMC requirements will limit projects to temperatures between 50 and 85 °F; in Ohio, the range limits are between 45 and 85 °F. In Michigan, concrete overlay cannot be used in the winter. In Utah, the daytime evaporation rate can create some issues, and hydrodemolition is not allowed below 40 °F statewide.

In Illinois, construction work is limited to between November 15 and April 15. Additional constraints are placed on concrete work occurring either between December 1 and March 15 or if the ambient temperature drops below 45 °F. If any of these conditions are present, whether hydrodemolition is appropriate is assessed on a case-by-case basis. According to collected data, in Pennsylvania, once freezing temperatures are reached, hydrodemolition cannot be performed due to the use of water. LMC temperature requirements govern, as they are higher than freezing temperatures.

CHAPTER 5

Construction and Performance

This section discusses factors that influence construction and performance in hydrodemolition projects.

Construction

Hydrodemolition can be utilized for the entire bridge all at once or in phases. Ten agencies responded to this question. Of these, Michigan, Virginia, and Washington States use hydrodemolition only on the complete bridge; in other states it depends on various factors. For example, in Louisiana, most of the time the hydrodemolition work is broken down in various phases. For long, complex bridges, the main reasons to choose one approach over another are traffic, maintenance, and construction sequences. In Pennsylvania, if the bridge can be detoured with a reasonable distance, then it would be closed to perform the work; otherwise, phased construction is used. Also, it is preferred to close the bridge to place the latex full width. Many projects are performed in phases based on traffic volumes and detour length.

Ohio uses both methods, depending on the situation for the structure (e.g., number of lanes). Utah also utilizes both approaches; a crossover works well and provides more space for hydrodemolition activities, creating a safer work environment. In Kentucky, it depends on MOT or other project constraints. In North Carolina it depends on reference traffic control plans (phasing depends on the overall project).

According to the collected data, equipment redundancy is not required of contractors in any of the participating states. However, agencies can have qualification requirements for those performing the hydrodemolition work. In Illinois, contractors need to show that they have the required equipment and experience to perform the work. In Louisiana, 60 days prior to beginning work, contractors must submit to the professional engineer for review a list of at least three different projects in the prior three years where the proposed hydrodemolition contractor and supervising staff successfully performed hydrodemolition on an area similar in size and magnitude (or larger) than the proposed project. However, Pennsylvania and Ohio have no prequalification requirement for hydrodemolition work; the only issue is that the contractor must have verifiable knowledge and experience. Furthermore, most of the state agencies (Illinois, Michigan, Minnesota, Pennsylvania, Virginia, and Washington State) do not have a prequalified list of contractors for hydrodemolition. Ohio, however, has a list of prime contractors (currently 10) from which to choose.

The collected data revealed that in all the states a test section is required before hydrodemolition begins on the deck. In Illinois, two 30-square-foot test sections are done first and used to calibrate the equipment. One section is in an area of sound concrete, and one is in area of unsound concrete. If the equipment does not appear to be reliably removing concrete (i.e., too much or too little), a third test section is performed on an area of sound concrete. Louisiana uses a similar procedure. Prior to commencement of the removal operation, the hydrodemolition equipment needs to be calibrated on two areas of sound concrete of at least 30 square feet each on the work area. The test sections should demonstrate that the equipment, personnel, and methods of operation are capable of conforming to the contract. Those tests are used to calibrate the equipment for removing the concrete to the specified depth in one pass of the equipment. When satisfactory results are obtained, these settings are recorded and used for production. If mechanical milling is proposed to be used, milling needs to be performed during test operations. The following settings should be recorded, as a minimum:

- Water pressure
- Machine staging control (step)
- Nozzle size and speed (travel)

Any equipment not demonstrating the ability to produce the specified results, as determined by the professional engineer, should be removed from the project and replacement equipment should be provided.

Agencies may require repair of damaged epoxy coating with an approved epoxy material during hydrodemolition. According the collected data results, among the nine responses provided for this question, four agencies (Illinois, Louisiana, Minnesota, and Ohio) do not have any requirement for repairing damaged epoxy coating. Virginia has no requirement for repairing the coating, but any loose epoxy coating should be removed. Kentucky requires that damaged epoxy coating be repaired with an approved epoxy material; however, most of the decks this state is rehabilitating are black steel. Michigan also has a requirement for repair and removal of epoxy from the bar.

In hydrodemolition projects, agencies may specify a certain depth of removal or calibrate to a certain concrete quality removal. Michigan utilizes both approaches. In Ohio, a minimum of 1 inch (measured to valley) is required; also, all unsound concrete should be removed. The depth of the removal in Utah is up to bottom of the top rebar. However, in Virginia, the quality of the concrete is the main criterion.

In Louisiana, concrete should be removed to the limits shown in the plans, and a highly rough and bondable surface should be provided for areas that will receive a concrete overlay or will be required to be bonded to concrete. Unless otherwise noted in the plans, mechanical milling will be allowed for initial deck removal provided no contact is made with the top mat of steel. If the reinforcing steel is damaged during the milling operations, this method of concrete removal should immediately cease, and hydrodemolition should be used for all remaining concrete removal.

In Minnesota, hydrodemolition equipment should be provided on a self-propelled machine that utilizes a high-pressure water jet stream capable of removing concrete to a half inch minimum depth beyond the scarified concrete and be capable of removing rust and concrete particles from reinforcing steel. In Washington State, half an inch of good bridge deck concrete should be removed.

Agencies may provide some guidelines or guidance for construction inspection. In Louisiana, the inspector guidelines are contained in the specification requirements, beginning with the qualifications, equipment testing, and test sections. In Minnesota and North Carolina, the engineer of record provides guidance and specification review during preconstruction meetings or in-house training is made available to consultant inspectors. In Washington State and Ohio, the requirements are spelled out in the standard specifications and construction administration manual provided to all inspectors. In Virginia, training is done by the bridge division as the agency has no construction division.

State agencies allow nighttime hydrodemolition with special requirements related to issues associated with working at night. According to the collected data, among the 10 responses the team received on this issue, nighttime hydrodemolition is allowed in all states (Louisiana, Michigan, Minnesota, North Carolina, Ohio, Pennsylvania, Utah, Virginia, and Washington State) but Idaho. When removal is performed during nighttime hours in Louisiana, adequate lighting must be used as required to allow for the safe conduct of nighttime removal operations. Lighting should be placed in accordance with the demolition and disposal plan, and care must be taken to avoid producing hazardous glare in the direction of oncoming traffic. In Ohio, contractors need to submit lighting plans 15 days in advance. Minnesota has no prohibition against nighttime hydrodemolition except that mandated by local noise ordinances.

State agencies may require a specific pre-activity meeting before starting hydrodemolition. However, in Louisiana, a preconstruction meeting is held for some projects to discuss hydrodemolition requirements, including qualifications, permits, testing requirements, and traffic control. Follow-up meetings are typical when a particular subcontractor is not present at the initial meeting.

In North Carolina, the contractor must submit a plan at the preconstruction meeting that outlines:

- Estimated depth of rebar
- Deck scarification plan
- Lighting plan
- Plan for profile and depth
- Field verification (require fill block under screed to verify adequate removal)
- Planned equipment

Washington State and Pennsylvania do not hold a pre-activity meeting. However, Washington State does specify a trial before scarifying the entire bridge. Pennsylvania conducts a preletting meeting.

For hydrodemolition projects, some special bracing considerations might be given for supporting the deck overhang. The collected data revealed that out of nine states, six (Louisiana, Minnesota, Ohio, Pennsylvania, Virginia, and Washington State) do not have any specification about this issue. In these states, bracing for overhang is handled with the other formwork submittals and is not specific to the hydrodemolition work. In Illinois, special bracing may be added if the amount of removed concrete is substantial. However, in Utah, providing special bracing considerations for overhang is required for all projects. In North Carolina, if the overhang is greater than 0.6 square foot per foot, then supplemental support is required.

Performance

One of the important factors in hydrodemolition projects is the performance and the life of a deck repaired using hydrodemolition. Louisiana estimates 15 to 20 years; Michigan estimates 40 years for shallow and 50 years for deep rehabilitations; North Carolina estimates more than 25 years for LMC overlays; and Ohio anticipates 20 years for new bare deck, 20 to 25 years for the first overlay and 15 to 20 years for a second overlay. According to Pennsylvania, the deck life is extended essentially to the life of the latex overlay(s), and an estimated life of the latex overlay is 15 to 25 years based on traffic volumes and the deck's prior condition. Pennsylvania also believes that a second process of hydrodemolition and overlay further extends the deck life. Utah estimates that the life of a deck repaired using hydrodemolition is between 20 and 25 years, compared to pothole patching, which lasts five to10 years. Most anecdotal evidence in Washington State leads to the expectation that decks repaired using hydrodemolition have a 30- to 40-year lifetime.

Agencies may have requirements for post-installation testing. According to the collected data, among eight agencies that provided responses for this issue, four (Louisiana, Minnesota, Virginia, and Washington State) do not have any specific testing for hydrodemolition projects after installation. However, Pennsylvania performs the bond adhesion test to ensure that the new overlay adheres to the existing deck properly. In Ohio, there is more detailed testing for hydrodemolition projects. After hydrodemolition, sounding tests are done, unsound concrete is removed, overlay is then placed, and the deck is checked visually. If cracks are found the deck is flooded to find the cracks; the deck is then sealed. Illinois and North Carolina perform pull-off tests to ensure that the new overlay adheres to the existing deck.

Some of the states (Louisiana, Minnesota, Michigan, and Washington State) have not conducted any research on hydrodemolition specifically. However, a few states have completed some research. In 2013, Kent Harries, Matthew McCabe, and Michael Sweriduk of the University of Pittsburgh, PA, conducted research titled "Structural Evaluation of Slab Rehabilitation by the Method of Hydrodemolition and Latex Modified Overlay [1]." In Ohio, a research project is ongoing about the effectiveness of hydrodemolition and polyaspartic sealing for bridge parapet and walls. Previously, they have conducted research about deck repair maintenance methods.

Virginia DOT is conducting research titled "Field Evaluation of Reinforced Concrete Repairs using Hydrodemolition, Galvanic Cathodic Protection, or Impressed Current Cathodic Protection." The purpose of this research is to evaluate the removal of delaminated and deteriorated concrete on the piers and caps of five different bridges along I-64 between Richmond and Charlottesville. In Ohio, one ongoing research project is investigating the effectiveness of hydrodemolition and polyaspartic sealing for bridge parapet and wall; one research project on deck repair maintenance methods has been completed.

1 Structural Evaluation of Slab Rehabilitation by the Method Of Hydrodemolition and Latex Modified Overlay, December 2013, Pennsylvania Department of Transportation, https://www.penndot.gov/ProjectAndPrograms/Planning/Research-And-Implementation/Documents/StructuralEvalOfSlabRehabBy-MethodHydrodemolition-LatexModifiedOverlay-FinalRpt.pdf

CHAPTER 6

Findings, Conclusions, and Recommendations

The following primary findings, conclusions, and recommendations were drawn from this study.

Findings

Conversations with various DOTs reinforced the fact that hydrodemolition has been successfully used in multiple states for many years, and multiple states have mature specifications for hydrodemolition. As mentioned earlier in this report, of the states participating in the scan, three mentioned that there is no major obstruction to use of this method, that it is standard practice, is widely used based on cost and deck condition, and specifications are regularly updated to keep up with current practice. However, as mentioned by two of the participating states, environmental concerns and noise issues were a common problem. The shortage of qualified contractors is a roadblock as is a lack of knowledge and training, standard practices guidance, and contract enforcement methods. Other concerns included cost of mobilization, unknown durability, benefit for life-cycle costs, limited budgets, and water availability.

Two basic classes of hydrodemolition are used: shallow removal and deep removal. Both classes can be effective, and the selection is principally one of economics. Following hydrodemolition, the states participating in this scan used one of several options for the material used to replace the hydrodemolished concrete. The choice of materials is largely impacted by the depth of removal.

Conclusions

Based on discussions during the scan the team came to the following conclusions:

- Hydrodemolition can be an effective tool for a bridge preservation program.
- The optimum time to utilize hydrodemolition is likely when the deck is between 5% and 20% deteriorated.
- The primary reason for using hydrodemolition is the characteristics of the surface remaining:
    - It is free of microcracks.
    - There is notable roughness.
- The long-term performance of a deck that has been rehabilitated with hydrodemolition is dependent upon the curing of the replacement material.
- Hydrodemolition is most cost-effective when utilized in combination with mechanical removal methods for the initial surface preparation.
- Hydrodemolition should be utilized as part of a holistic deck preservation program.

- Monitoring deck condition and implementing hydrodemolition at the right time is important to achieving a deck that can achieve multiple "lives."
- Multiple states have mature deck preservation programs; these should serve as starting points for other states.

Recommendations

The use of hydrodemolition can be considered mature and practice-ready based on the experiences of the agencies participating in the scan, and there are existing practices for ensuring quality.

The scan team has identified actions that several DOTs have taken to make hydrodemolition a valuable tool for DOT managers and engineers to use in their bridge preservation efforts. The following suggestions are made to share the benefits of using hydrodemolition, to increase the knowledge base so that hydrodemolition can be judiciously and effectively deployed, and to address barriers that exist.

- Document presentations from states in a concise but complete report.
- Promote and describe hydrodemolition via technical webinars. The team plans to work with the Transportation Research Board (TRB) and American Association of State Highway and Transportation Officials (AASHTO) to produce a webinar series.
- Make presentations to various AASHTO committees to further promote the adoption and use of hydrodemolition. Presentations are also planned to be made at various other professional conferences to provide technical information to highway professionals on the advantages associated with the use of hydrodemolition for bridge preservation projects.
- Investigate the possibility of developing Internet-based tools for gathering information from bridge owners on their experiences and practices in using hydrodemolition.
- Identify additional knowledge gaps beyond those disclosed as a part of this peer exchange, with the goal of developing National Cooperative Highway Research Program (NCHRP) research topics. Examples the scan team identified include the need to address environmental concerns and noise issues, a lack of knowledge and training, standard practices guidance, and contract enforcement methods.
- Develop training tools to help transfer knowledge from experienced to newer employees within agencies. Training tools are also needed for the private sector, as a major roadblock the participants identified was the shortage of qualified contractors. Training could take the form of webinars, design examples, documented/instituted succession plans, and mentorship programs.
- Plan and hold discussions between team members and the AASHTO Committee on Bridges and Structures about AASHTO load and resistance factor design (LRFD) specifications addressing hydrodemolition.

Contained in this report are appendices intended to share additional information from the workshop. The appendices provide:

- Case studies on projects in Pennsylvania and Michigan using hydrodemolition (**Appendix A**)
- Contact information for the scan team members who were active in this study (**Appendix B**) and brief biographic sketches (**Appendix C**)
- Identification of lead states that presented their experiences in using hydrodemolition (**Appendix D**)
- The amplifying questions the team provided to the states that participated in this scan (**Appendix E**)

Scan team members will provide a summary of the team's findings at technical conferences and meetings within their home state and nationally. The information obtained will be readily available to FHWA, state DOTs, local bridge owners, authorities, other federal and local agencies, the construction industry, university researchers/students, and consultants. Team members will look for opportunities to communicate the scan's findings locally and as a coordinated effort at the national level.

The team has developed a detailed dissemination plan with specific actions. It contains events such as the AASHTO Committee on Bridges annual meeting, American Society of Civil Engineers section meetings, the International Bridge Conference, sponsored by the Engineers' Society of Western Pennsylvania, the TRB annual meeting, and Transportation System Preservation Technical Services Program (TSP2) national and regional meetings.

Hydrodemolition is an extremely valuable strategy that has proven benefits to those who have used it, and it can truly benefit those who have not used it if they are made aware of these findings.

Appendix A: Case Studies: Pennsylvania and Michigan

Case Study: Pennsylvania DOT

Overview

The Pennsylvania DOT (PennDOT) includes 11 districts and a central office. Bridge preservation and rehabilitation techniques are discussed, and guidance is provided in PennDOT design manuals; however, decisions for project scopes of work are made at the district level. PennDOT routinely utilizes hydrodemolition with LMC overlays for bridge deck rehabilitation. It is cost effective versus a bridge deck replacement, can be performed over a weekend if necessary, and is a good solution for bridge decks with high average daily traffic. The PennDOT standard LMC overlay is a shallow overlay with fast-track hydrodemolition. PennDOT standard specifications are included in this appendix.

Scoping, Planning, and Design

LMC overlay candidates are typically structures with decks at a condition rating greater than 4. PennDOT design manuals provide guidance with deck overlays. The deck overlay decision tree is included in this appendix. Most structure types are candidates, although there are concerns with concrete-filled steel grid decks and structures with large deflections.

When the scope of work for a structure includes an LMC overlay, a design inspection is performed. The deck is sounded to determine the extent of unsound areas. The underside of the deck is also inspected. PennDOT uses stay-in-place forms. Inspectors look for rusting stay-in-place forms and spalled areas on the underside of the deck. The extent of the unsound areas is used to determine the potential for full-depth repair areas. Designers typically use 5% to 10% of unsound areas to calculate quantities for full-depth repair areas. The design inspection is also used to determine variable-depth LMC quantities. Variable-depth quantities are discussed in Construction and Problems Encountered and Solutions in this case study. Cores are taken to determine chloride content, although this is seldomly done.

Maintenance and protection of traffic is evaluated during design for all projects; with LMC overlay projects, it is a limited concern. Because PennDOT utilizes shallow overlays, hydrodemolition is routinely performed over traffic. PennDOT specifications require contractors to provide protective shielding. LMC overlays are performed with full detours in place, and they are also performed in phases (**Figure A-1**).

Figure A-1 Example of phased construction: SR 51 A79 Elizabeth Bridge (District 11) (Pennsylvania DOT)

During design, it needs to be determined if the LMC will match existing deck elevations or if raising the deck is necessary. PennDOT typically maintains deck elevations and avoids adding deck thickness. When maintaining grade, the load ratings are not affected. Raising the grade requires the load ratings to be checked and most likely will result in a less uniform LMC thickness.

Structures to receive an LMC overlay should be analyzed for construction loadings. Because the hydrodemolition process may involve tanker and vacuum trucks on the structure, construction loadings and configurations should be obtained and analyzed. If necessary, arrangements should be made to stage equipment off the structure. Walk-behind vacuum equipment can be specified. Fully loaded LMC mobile mixer trucks drive onto the prepared surface to place LMC and should be analyzed as well.

Construction

When an LMC overlay is included on a project, construction consists of scarification in passes that are a one quarter inch or one half inch deep, hydrodemolition, LMC overlay, and mechanical texturing. Before the removal process begins with scarification and hydrodemolition, bridge decks are reviewed for potential full-depth removal areas. Even though removal depths are typically shallow on PennDOT projects, full-depth unsound areas can be encountered. Proper protective shielding must be in place before operations begin. A water containment plan is required.

As mentioned previously, PennDOT typically maintains deck elevations with the LMC overlay process. This requires a minimum of 1¼ inch removal of the top surface of the existing deck because the minimum LMC overlay thickness is 1¼ inch.

Scarification is the first step for removal and is required to open up the deck surface in preparation for hydrodemolition. Scarification is a more economical way to remove the top portion of the deck instead of hydrodemolition alone. When hydrodemolition is specified on a project, scarification can be performed in half-inch passes. When hydrodemolition is not specified, one quarter inch maximum-depth passes are required. It is seldom that PennDOT projects do not include hydrodemolition. Scarification alone can cause microcracking of the deck surface that could affect the bond of the overlay; one quarter-inch passes reduce this concern. However, with hydrodemolition there is far less risk of a bond failure and is why it is standard practice for LMC overlays on PennDOT projects. Standard practice is two half-inch scarification passes over the deck surface for a total of 1 inch of removal. Scarification is a square yard item.

The second step for removal is performing hydrodemolition to provide a rough and bondable surface. Hydrodemolition is calibrated on each bridge deck to remove a one quarter inch of sound concrete and any unsound concrete present. The one quarter inch of sound concrete removal is measured from the scarified surface to the peaks of the roughened hydrodemolitioned surface. Hydrodemolition is calibrated on an approximately 7 foot by 7 foot area of sound concrete. Water pressure, nozzle track travel speed, water usage, and nozzle size are documented. Water pressure typically ranges from 14,000 to 16,000 psi. Track speed (measured in seconds) varies based on the size of the equipment used. Water pressure and track speed are the primary factors in calibration. These factors are adjusted as necessary to provide a one quarter inch of removal.

Once the machine has been calibrated on an area of sound concrete (**Figure A-2**), it is moved to an area of unsound concrete. In most cases, the settings for sound concrete will remove a partial depth of unsound concrete. These settings help with minimizing "blow outs" or full-depth removal with the hydrodemolition machine. The settings are enough to remove partial depth but most often not enough in areas with full-depth unsound concrete. When the bottom mat of reinforcement bars is encountered, the remaining concrete is removed with 30 foot-pound pneumatic chipping hammers. Water pressure and track speed are easy for inspectors to monitor by checking the gauges and using a stopwatch or simple timer on a smart phone. After hydrodemolition is complete, areas not accessible to the hydrodemolition machine (e.g., gutterlines) are removed and roughened with 30 foot-pound pneumatic chipping hammers. Hydrodemolition is a square-yard item.

Figure A-2 Example of hydrodemolition machine calibration (Pennsylvania DOT)

Before placing the LMC overlay, the hydrodemolitioned deck surface is reviewed for deeper areas of removal. Typically, deeper areas of removal are placed concurrently with the LMC overlay. Areas exceeding 4 inches in depth and full-depth areas are placed before the LMC overlay. These areas are placed to match the adjacent hydrodemolitioned surface elevation. They are roughened and cleaned before LMC overlay placement. LMC slurry is brushed/ broomed onto the surface of the patches and gutterlines right before the LMC overlay is placed. Patches placed before LMC overlay are paid separately.

LMC overlays are typically placed with a Bid-Well[2] finishing machine (**Figure A-3**). PennDOT strives for a close placement operation. LMC is placed onto the deck no more than 5 feet ahead of the finishing machine. With LMC, it is best to minimize finishing or floating to avoid surface tearing. The goal is to have curing covers down within 15 feet of the finishing machine (**Figure A-4**). Because PennDOT primarily utilizes mechanical texturing, the curing covers can be placed quickly. Manual tining is not suggested for LMC overlays. LMC overlays are paid by the square yard. PennDOT has standard square-yard items ranging from 1¼ to 5 inches in depth, although 1¼ and 1½ inches are most common.

2 Bid-Well Bridge and Flatwork Paver, Terex, https://www.terex.com/bid-well/en/products/bridge-pavers

Figure A-3 Example of LMC placed with LMC mixer truck and finished with Bid-Well finishing machine (Pennsylvania DOT)

Figure A-4 Example of an LMC placement operation: placing curing covers behind finishing operation (Pennsylvania DOT)

When a 1¼ inch overlay is specified for a project, as mentioned previously, the removal consists of 1 inch of scarification and one quarter inch removal to the peaks of the hydro-demolitioned surface in sound areas. The minimum thickness of the overlay is 1¼ inch. A variable-depth item is included on PennDOT projects to pay for the LMC below the peaks of the hydrodemolitioned surface to the valleys and unsound removal areas. Because LMC trucks are calibrated mobile mixers, variable-depth quantities are determined by meter. Variable-depth LMC is a cubic-yard item.

Problems Encountered and Solutions

Structural Capacity

PennDOT and other DOTs were skeptical of the structural capacity of LMC and other types of overlays. Prior to 2013, PennDOT design manuals did not consider LMC as structurally effective. LMC overlays were placed by performing one quarter inch of scarification, hydrodemolition, and raising the deck elevation by 1 inch with the overlay. PennDOT strived to stretch the life of bridge decks, and some of the LMC overlay candidates had excessive delaminations. After hydrodemolition, excessive deeper removal areas on several projects were a cause for concern, and an evaluation of the structural capacity of LMC overlays was necessary.

The University of Pittsburgh performed a study to verify if the scarification, hydrodemolition, and LMC rehabilitation strategy results in a composite bridge deck. The study confirmed uniform capacity regardless of depth. All test specimens behaved in a composite manner. LMC-repaired slabs exceeded predicted capacities and the capacities of control slabs. The attached study provided best practices, including the following:

- Clean all debris and laitance from prepared surface
- Remove all shadows below rebar (**Figure A-5**)
- Avoid segregation during placement
- Follow proper curing procedures
- Hydrodemolition is the preferred method of concrete removal
- Requires minimum bond strength of 200 psi (PennDOT requires 250 psi)

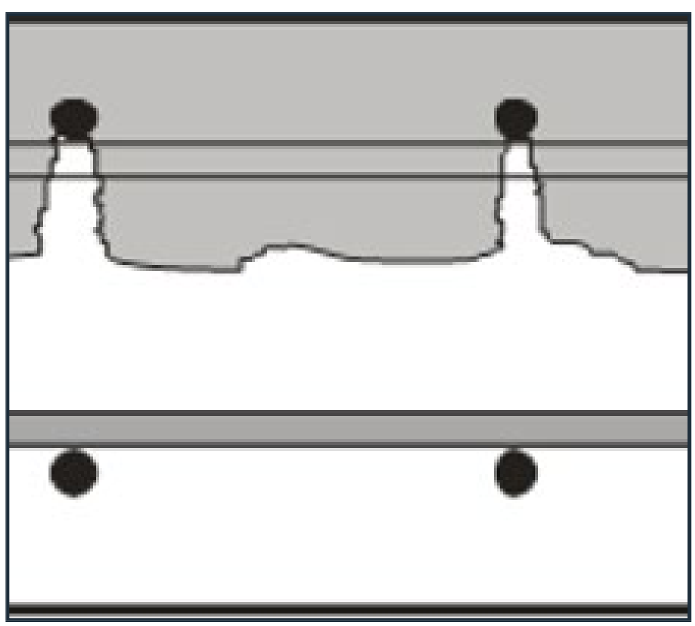

Figure A-5 Concrete shadows (Pennsylvania DOT)

With the results of the study, PennDOT revised design manuals to consider LMC overlays as structurally effective provided the overlay is a minimum of 1¼ inch thick. This led the PennDOT process to become a rehabilitation of the deck more than just an overlay, allowing deck elevations to be maintained and not increased.

LMC Overlay Cracking

LMC overlays can sometimes crack after placement. PennDOT has standard specifications for evaluating cracking. Most often the cracks are nonstructural. When the bond strength is over 250 psi and cracks are nonstructural, PennDOT has determined that high-molecular-weight methacrylate is the best crack filler/sealer.

Estimating Variable-Depth Quantities

When new to the LMC overlay process, estimating variable-depth quantities can be a challenge. After reviewing several sites, design and construction engineers work together to determine standard estimating practices. PennDOT typically estimates one half to 1½ inches over the entire deck area to calculate cubic yard volume for variable-depth LMC.

Concluding Remarks

With tight budget constraints, PennDOT continuously works to improve preservation techniques to increase the life of bridge decks. PennDOT views concrete overlays with a bond strength 250 psi or greater to be composite with the original substrate. The PennDOT LMC process has evolved from a true overlay to a rehabilitation of the top portion of the deck. Elevations are maintained, and no additional dead load is added to the deck. Hydrodemolition provides a fast, efficient way to remove unsound concrete and provide a rough and bondable surface for LMC.

Example Project

An example of the PennDOT standard LMC overlay with hydrodemolition surface preparation is the State Route (SR) 65 project in PennDOT District 11, Beaver County. This project included scarification, hydrodemolition, and LMC overlay on the SR 8029 ramp structure. Work was performed during the 2017 construction season. (See **Figure A-6**.)

- Location: SR 8029, 3rd Avenue Ramp to SR 65 Southbound, Freedom Borough, Beaver County, Pennsylvania
- Structure ID: 04-8029-0020-0089
- BRKEY: 3920
- Year built: 1975
- Span information: 8 span stringer/girder bridge, 798 feet, max span 125 feet
- SR 8029 ramp structure scope of work for bridge deck:
    - Replace armored compression seals with neoprene strip seal dams.
    - Perform scarification, two half-inch passes, removing 1 inch of deck thickness.
    - Perform hydrodemolition, one quarter-inch removal in sound areas, removal of unsound concrete.
    - Perform Type 3 (full depth) repairs if hydrodemolition exposes bottom mat of rebar. Place concrete to match the elevation of adjacent hydrodemolitioned surface. Remove laitance and roughen Type 3 patches before overlay placement.
    - Place LMC overlay, 1¼-inch minimum depth, deeper in areas where unsound concrete was removed.
    - Where unsound concrete was removed (other than Type 3 full-depth repair areas), place LMC monolithically with overlay placement.
    - Variable depth actual quantity: 76.98 cubic yards (1.34 inches over deck area)
    - Mechanically texture/groove the bridge deck. Longitudinal mechanical texturing specified.

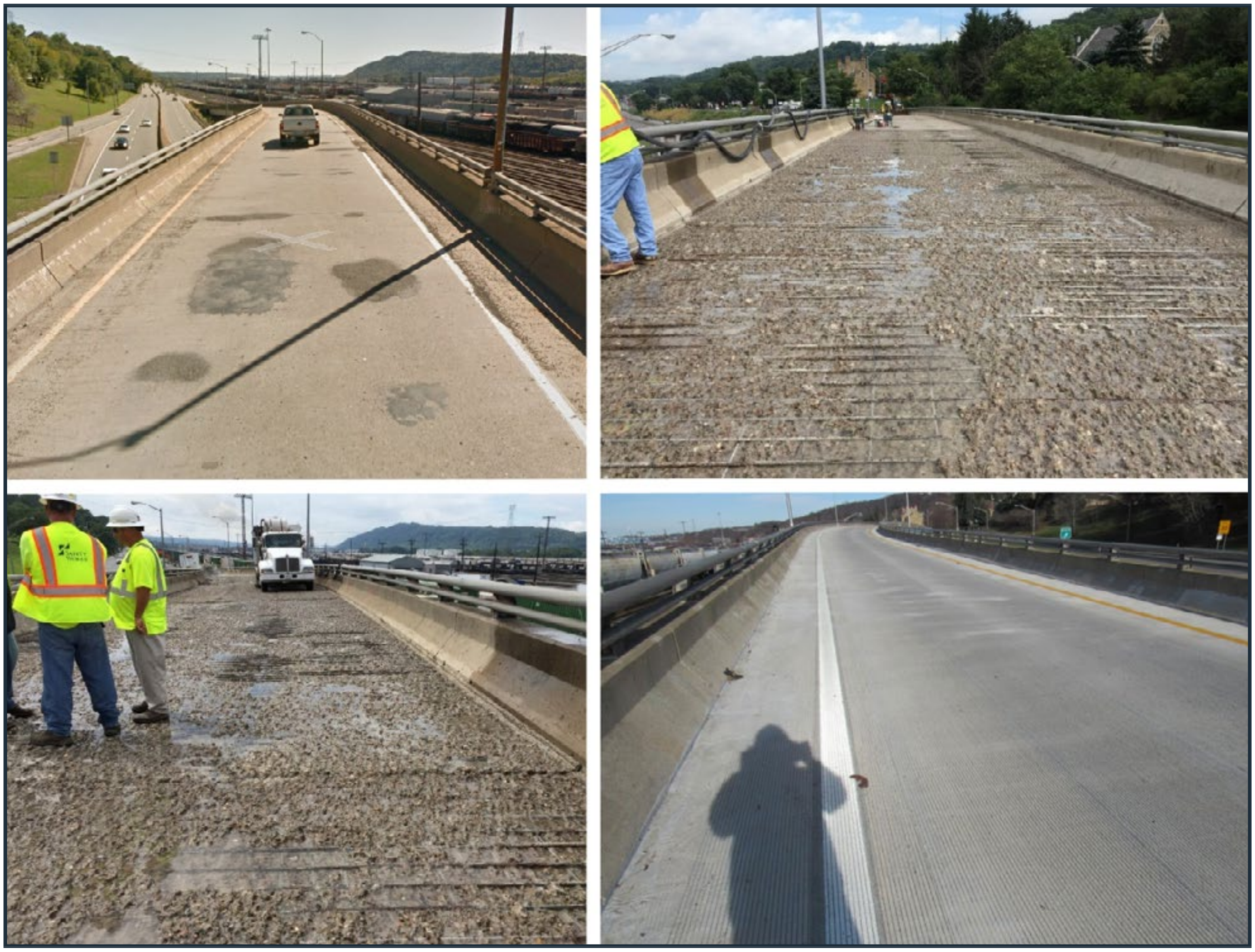

Figure A-6 SR8029 project (left to right, top to bottom): a) before preservation project, b) and c) after scarification and hydrodemolition, and d) after LMC overlay (Pennsylvania DOT)

Attachments to Pennsylvania Case Study

Excerpts from the Commonwealth of Pennsylvania Department of Transportation Publication 408/2020 Specifications[3]

SECTION 1039—CONCRETE BRIDGE DECK SURFACE PREPARATION, HYDRODEMOLITION

1039.1 DESCRIPTION—This work is bridge deck surface preparation after scarification using hydrodemolition to provide a rough and bondable surface and to remove unsound concrete. This work includes the removal and disposal of concrete and debris, vacuuming, shielding, water control, jackhammering and chipping, and work necessary for preparing the deck for completing concrete bridge deck repairs and the placement of a new latex modified concrete wearing surface as indicated and directed.

1039.2 MATERIAL—Not used.

1039.3 CONSTRUCTION—

(a) General. Submit a hydrodemolition water control plan to the structure control engineer for review and approval for control and filtering of water discharged during the hydrodemolition operation. Include in the submission the maximum and minimum water pressure (pounds per square inch) and water usage (gallons per minute) the hydrodemolition machine will provide. Provide settlement basins or devices to allow only visibly clear water from leaving the project site. Protect scuppers, inlets, and downspouts from material that would cause plugging. Provide free-flowing, unobstructed drainage structures at the completion of this operation

Provide a technical field representative on the project site during the calibration and the hydrodemolition surface preparation operation.

(b) Equipment

1. **Hydrodemolition Equipment**. The hydrodemolition equipment is required to be a computerized, self-propelled machine that utilizes a high-pressure water jet stream to provide a rough and bondable surface while removing unsound concrete, rust, and concrete particles from exposed reinforcement during the hydrodemolition operation.

1.a Calibration. Completely remove construction debris, scarification debris, and dust from the bridge deck surface before calibration.

Calibration is required each time hydrodemolition surface preparation is performed and as required to achieve the results specified.

Before commencement of the hydrodemolition surface preparation operation, calibrate the hydrodemolition equipment on an area of sound concrete (7 foot x 7 foot) as

3 Commonwealth of Pennsylvania Department of Transportation Publication 408/2020 Specifications, Initial Edition, effective April 10, 2020, http://www.dot.state.pa.us/public/PubsForms/Publications/Pub_408/408_2020/408_2020_IE/408_2020_IE.pdf

designated by the structure control engineer to demonstrate that the hydrodemolition equipment can provide a rough and bondable surface. Calibrate hydrodemolition equipment to remove no more than one quarter inch of concrete (original deck surface to peaks of roughened surface) in sound areas.

bondable surface. Calibrate hydrodemolition equipment to remove no more than one quarter inch of concrete (original deck surface to peaks of roughened surface) in sound areas.

Move the hydrodemolition equipment to a second area (7 foot x 7 foot) that is unsound as designated by the structure control engineer to demonstrate that the hydrodemolition equipment can provide a rough and bondable surface while removing unsound concrete in one pass. Adjust the settings as required within the limits established below to achieve total removal of unsound concrete.

Provide verification of the following settings to the representative:

- Water pressure gauge (pounds per square inch [psi])
- Water usage (gallons per minute)
- Machine staging control (step)
- Nozzle size
- Nozzle speed (travel)

The hydrodemolition surface preparation production may begin after the structure control engineer accepts the calibration and production settings. Maintain and provide the calibration and production settings to the representative before and during hydrodemolition surface preparation production.

If unsatisfactory results are obtained, stop hydrodemolition until the equipment deficiency or malfunction is corrected. Provide another hydrodemolition unit for calibration if onsite equipment deficiencies cannot be corrected at no additional cost to the department. No additional contract time will be provided for equipment deficiencies, malfunctions, or recalibration of another hydrodemolition unit if required.

2. **Pneumatic Hammers**. In areas inaccessible to hydrodemolition units or where the provided coverage is insufficient, use pneumatic hammers not exceeding 30 foot-pounds, operated at no more than a 45-degree angle from horizontal. Hand-held water-blasting equipment capable of delivering a minimum of 25 gallons per minute at 10,000 psi are also allowed. Use chipping hammers not exceeding 15 foot-pounds or hand-held water-blasting equipment when removing concrete within one inch of the reinforcement steel.

(c) Surface Preparation Before Hydrodemolition. Provide shielding, as required, to ensure containment of dislodged concrete within the removal area to protect property and the

traveling public from flying debris on, adjacent to, and below the work site.
Perform scarification as specified in Section 1041 on the bridge deck before hydrodemolition. Remove construction debris, scarification/milling debris, and dust completely from the bridge deck surface before commencement of the hydrodemolition surface preparation operation.

(d) **Hydrodemolition.** Perform hydrodemolition surface preparation over the entire top surface of the bridge deck or locations indicated to provide a rough and bondable surface and to remove unsound concrete in one pass. Verify and document removal every 30 feet along the cutting path. Do not allow vehicles other than approved construction equipment on those sections of deck where hydrodemolition has begun. Prevent contamination of the deck by providing protection for hydrodemolished portions of the deck.

Stop the surface preparation operation if it is determined that sound concrete is being removed in excess of one quarter inch (scarified deck surface to peaks of roughened surface in sound areas) or unsatisfactory results are being obtained, as determined by the representative. Perform recalibration or changes in equipment and methods before resuming the operation.

(e) **Cleaning.** Clean the hydrodemolition debris with a vacuum system equipped with fugitive dust-control devices and capable of removing wet debris and water in the same pass. Cleaning includes, but is not limited to, fine material, powder, dust, water, and particles in pockets, voids, and crevices that would hinder an overlay from bonding with the substrate. Use oil-free compressed air to remove excess water and to dry the deck. Perform cleaning before debris and water dries on the deck surface. Remove material allowed to dry at no additional cost to the department.

(f) **Deck Sounding Verification**. After the hydrodemolition surface preparation operation has been performed and the deck is dry and clean, resound the deck to ensure unsound material has been removed, with the exception of Type 3 concrete bridge deck repair removal areas. Perform the remaining removal for Type 3 concrete bridge deck repair areas as specified in Section 1040 and as directed. Unsound concrete is defined as existing bridge deck concrete that is deteriorated, spalled, or determined by the representative to be unsound. Remove remaining unsound concrete, patching material, or existing unsound overlay, as determined by the representative, with pneumatic hammers or hydrodemolition at no additional cost to the department. Use pneumatic hammers to provide a rough and bondable surface in areas that are inaccessible to hydrodemolition equipment. Remove unsound concrete or original deck surface found after the hydrodemolition surface preparation operation at no additional cost to the department.

(g) **Reinforcing Steel**. Protect exposed reinforcement bars from bending by providing adequate supports. Splice or replace reinforcing steel damaged, bent, or dislodged by the hydrodemolition operations with the same size bar at no additional cost to the department. Repair reinforcing steel distorted as a result of contractor operations at no additional cost to the department. Remove portions of heavily corroded reinforcement steel where less than one half of the effective cross-sectional area remains. Replace with the same type and size of bars as specified in Section 1002.3 and as directed. The requirement to provide a minimum three-quarter-inch clearance around reinforcement bars that are more than one half of the diameter exposed is waived, provided the existing substrate concrete is sound. Where more than one half of the diameter of the reinforcement bar is exposed, and the bar is corroded around the circumference, adjacent concrete is rust stained, or the bar is debonded from the substrate concrete, chip away concrete or water blast to provide a minimum three quarter-inch clearance.

1039.4 MEASUREMENT AND PAYMENT—Square yard of deck area regardless of the number of passes.

SECTION 1041—SCARIFICATION

1041.1 DESCRIPTION—This work is scarifying existing concrete bridge decks in one or multiple passes as indicated to the overall uniform depth in preparation for placing a concrete or mortar wearing surface or before performing hydrodemolition surface preparation.

1041.2 MATERIAL—Not used.

1041.3 CONSTRUCTION—

(a) General. Submit for acceptance the proposed method and equipment used for scarification of concrete surfaces. Before scarification, perform a precondition survey of the existing concrete bridge deck cracks to locate potential reflective cracks in the wearing surface. Perform a bridge deck survey as specified in Section 1042.3(b).

Do not perform scarification on new concrete until a compressive strength of 3,300 psi is attained. Verify the cover of the top mat of reinforcement bars before scarification. Scarify the existing concrete bridge deck the number of uniform depth passes indicated to the required overall removal depth. When hydrodemolition is not indicated, perform scarification in one-quarter inch maximum uniform depth passes. When hydrodemolition is indicated, perform scarification in one-quarter inch or one-half inch uniform depth passes as indicated.

If the overall removal depth indicated was not achieved, perform additional scarification to the overall removal depth at no additional cost to the department. When existing overlays are present or are indicated for removal, do not demobilize the scarification equipment until the representative verifies the removal depth and complete removal of existing overlays up to one half inch to the top mat of reinforcement bars. Do not scarify within a one half inch clearance of the top mat of reinforcement bars. Clean the deck surface as directed for verification of the removal depth and to ensure existing overlays were completely removed or the deck has been removed to one half inch of the top mat of reinforcement bars.

In areas inaccessible to scarification equipment, use pneumatic hammers not exceeding 30 foot pounds, operated at no more than a 45 degree angle from horizontal to remove the required depth indicated. Do not use triple-headed tampers fitted with star drills less than 2 inches in diameter.

Completely remove by hand, power broom, or vacuum all broken concrete and laitance resulting from the scarification operation. Do not flush debris. Remove debris at the end of each workday. Clean debris from scuppers and downspouts as needed. Do not allow construction vehicles or equipment, other than power brooms, on the scarified deck surface, unless the surface is adequately protected to prevent contamination.

(b) **Equipment**. Scarify using a self-propelled machine capable of preparing 1,000 square yards per day. The equipment used for scarification is required to remove the single-pass depth indicated across the cutting path. A micromill milling machine is required when scarifying before placing a polyester polymer concrete overlay.

1041.4 MEASUREMENT AND PAYMENT—Square yard for the single-pass depth indicated.

Payment will only be made for the surface area of each uniform single-pass depth indicated and required to achieve the overall removal depth regardless of the number of passes made with the scarifying equipment.

SECTION 1042—LATEX MODIFIED MORTAR OR CONCRETE WEARING SURFACE

1042.1 DESCRIPTION—This work is construction of a latex modified mortar or concrete wearing surface on bridge decks, approach slabs, or indicated surfaces. The indicated or specified depth of the wearing surface is the minimum.

1042.2 MATERIAL—

(a) **Cement**. Type I, IP, IS, or II (MH), Section 701.1.

(b) **Fine Aggregate**. Type A, Section 703.1.

(c) **Coarse Aggregate**. Type A, No. 8, Section 703.2.

(d) **Water**. Section 720.1

(e) **Latex Emulsion Admixture**. Section 711.3(e)

(f) **Latex Modified Mortar (LMM) or Concrete (LMC) Mix Design**. Use latex modified mortar for depths less than 1 1/4 inches. Use latex modified concrete when the depth is 1 1/4 inches or more.

Provide a concrete technician as specified in Section 704.1(d)2. Provide testing facilities and equipment as specified in Section 704.1(d)3.

The term “latex,” as used in this Section, refers to latex modified mortar or concrete, unless otherwise specified.

Provide latex conforming to the following requirements:

Latex Modified Mortar or Concrete Mix Design Requirements	Requirements	
	Mortar	Concrete
Cement content, bags/cubic yard	8.0	7.0
Latex emulsion admixture modifier, gal/bag of cement	3.5	3.5
Air content, % of plastic mix (AASHTO T 152)	1 - 7	1 - 7
Water/cement ratio, by weight	0.35 - 0.40	0.30 - 0.40
Slump[(1)], inches (AASHTO T 119)	4 - 6	3 - 7
Percent fine aggregate as percent of total aggregate, by weight	100	60 ± 5
Cement/fine aggregate/coarse[(2)] aggregate ratio, by weight	1:3.25	1:2.5:2.0 to 1:2.9:1.6
5-day compressive strength (psi) (PTM Nos. 604 & 611)[(3)]	3,000	3,000
28-day compressive strength (psi) (PTM Nos. 604 & 611)[(3)]	3,500	3,500

(1) Discharge the sample from the mixer and transport it to a point unaffected by vibration. Deposit the sample on the deck in a suitable container and do not disturb for five minutes. Then, remix the sample and perform the slump test according to AASHTO T 119.

(2) Dry basis, aggregate specific gravity = 2.65. The dry weight ratios are approximate and should produce good workability, but due to gradation changes, the ratios may be adjusted within limits by the representative.

(3) Cure specimens according to PTM No. 611, Section 11.1, except strip after the first 48 hours (± 2 hours), and air cure as specified in Section 1042.3(d) Table A.

Accelerated Latex Modified Concrete Mix Design Requirements	
Cement	Type I, IP, or II, Section 701.1 or other rapid setting cement accepted by the DMM/DME
3 Hour Minimum Compressive Strength	3,000 psi
12 Hour Minimum Compressive Strength	3,000 psi

1. **Compatibility Testing During Mix Design.** Verify the compatibility of the mix components during mix design and ensure that the mix provides sufficient time of workability to satisfactorily finish and texture the surface. Re-verify compatibility whenever there is a change in mix components. Provide a technical expert from the latex admixture manufacturer for the design process, if directed.

(g) Mix Designs Using Potentially Reactive Aggregates. Section 704.1(g)

1042.3 CONSTRUCTION—

(a) Equipment. Obtain acceptance of equipment for the deck preparation, mixing, placing, and finishing of the latex wearing surface before start of wearing-surface work. Include equipment specifications in the QC Plan specified in Section 1042.3(c).

1. **Surface Preparation Equipment**. Of the following types:

   1.a **Abrasive Blasting or Water Blasting Equipment**. Capable of removing partially loosened chips of concrete and removing rust and corrosion from reinforcement bars. Provide water blasting equipment with a minimum rated capacity of 5,000 pounds per square inch.

   1.b **Power-Driven Hand Tools**. Section 1040.3(b)

   1.c **Scarification.** Section 1041.

   1.d **Hydrodemolition**. Section 1039.

2. **Proportioning and Mixing Equipment**. Provide self-contained, mobile equipment capable of continuous mixing, with the capacity to deliver a minimum of 6 cubic yards of latex per hour, and subject to the following:

   2.a **Mixing Equipment**. Provide equipment with a metal plate or plates permanently attached in a prominent place, plainly marked with the gross volume of the unit in terms of mixed mortar, operating speed, auger mixing angle, and the weight-calibrated cement constant of the machine, in terms of a revolution counter or other output indicator, all as rated by the manufacturer.

   2.b **Compartments**. Provide separate compartments to carry the necessary ingredients needed for the production of latex modified mortar or concrete. Cover aggregate bins at all times. Provide cement bins free of moisture and contamination at all times. Provide suitable means to carry water and additives on the truck and to incorporate the additives with the mixing water in the mix.

   2.c **Feed Systems**. Provide a unit with a feeder system mounted under the compartment bins to deliver the ingredients to the mixing unit. Provide each bin with an accurately controlled, individual gate to form an orifice for volumetrically measuring the material drawn from each respective bin compartment. Maintain belt feeders and scrapers to prevent leakage of materials onto the deck.

   Set the cement bin feeding mechanism to discharge continuously, and at a uniform rate, a given volumetric weight equivalent to cement during the mixing operation. Coordinate the aggregate feeding mechanisms with the cement feeding mechanisms to deliver the required proportions.

   2.d **Mixing Unit**. Provide an auger-type mixing unit, incorporated into the truck's discharge chute or other suitable mixing mechanism, capable of producing latex of uniform consistency and discharging the mix without segregation.

   2.e **Dials and Measuring Devices**. Equip the unit with an accurate revolution counter indicator allowing the reading of the volumetric weight equivalent to cement discharged during the mixing operation. Equip the counter with a ticket printout to record this quantity. Use aggregate dials that allow the setting of required openings for volumetric proportioning.

Equip the unit with a cumulative water meter and a water flow gauge to accurately indicate the discharge rate of water by volume (gallons per minute) entering the mix. Provide an approved device on the mixing unit for the representative to use to check the rate of flow of the latex modified admixture entering the mix along with the total amount of latex-modified admixture contained in the mix. Coordinate the water and additive measuring devices with the cement and aggregate feeding mechanisms. Equip the flow meters with scales appropriate for the type and amount of material being added.

Mount a tachometer on the mixing unit to indicate the drive shaft speed.

Place required indicating devices in full view and near enough to be accurately read or readjusted by the operator while latex is being produced. Provide the operator with convenient access to controls.

2.f **Calibration**. Provide a unit constructed to allow convenient calibration of the gate openings and meters. Have the calibration conducted by the supplier of the latex in the presence of the representative, and recalibrate after every 100 cubic yards of production for each unit. Document the calibration of Form CS-4342 and keep with the mobile mixer. Have the supplier of the latex make satisfactory arrangements with the representative at least 7 calendar days in advance of calibration. Provide platform scales calibrated annually. Calibrate using the maximum water/cement ratio, cement, and aggregates listed on the approved mix design. Verify compatibility of components and mix workability time while performing a yield test at the conclusion of the calibration process, if directed.

Conduct a recalibration in the event of a change in source of aggregates. Conduct additional calibration as directed. Have each approved unit carry a copy of the calibration certificate. In addition to calibration, perform a yield test according to AASHTO T 121, if directed.

An additional check may be made using the following procedure:

With the cement meter set on zero and controls set for the desired mix, activate the mixer discharging mixed material into a one quarter cubic yard container (36 inches by 36 inches by 9 inches). When the container is level-struck full, making provision for settling the material into corners, the cement meter is required to show a discharge of two bags of cement for modified mortar (eight bags per cubic yard mix) or 1¾ bags of cement for modified concrete (seven bags per cubic yard mix).

2.g **Mixing and Delivery Control**. Proportion, measure, and batch cement and aggregates by a volumetric weight equivalent method. In operation, the entire measuring and batching mechanism is required to produce the specified proportions of each ingredient. Establish volume/weight relationships during the calibration of the measuring devices. Provide tolerances in proportioning the various ingredients as follows:

- Cement, weight % 0.0 to +4.0
- Fine aggregate, weight % ±2.0
- Coarse aggregate, weight % ±2.0
- Water, weight or volume % ±1.0
- Latex, weight or volume % ±2.0

During mixing, maintain the drive shaft speed as indicated by the tachometer at operating speed ± 50 rpm. Set the auger mixer angle in the range determined by the manufacturer. Do not exceed one half hour for the interval between the continuous placement of successive batches. Equip the mixer to spray water.

2.h Loading. Charge aggregate bins no more than 6 hours before time of scheduled placement unless otherwise approved by the representative. Ensure the aggregate is maintained in a uniform wet condition before loading. Determine the amount of free water on the aggregates at the time of loading by performing aggregate moisture tests according to AASHTO T 255 or ASTM C70. Adjust mix proportions to account for the amount of available free water. Empty bins and recharge if not utilized within 6 hours or if conditions contribute to variable moisture content of the aggregate. Stock aggregates in a manner that prevents contamination.

Upon arrival at the project site, empty bins of aggregate that were charged before coming to the current project. Empty the cement bin and latex tank unless use on a previous project can be verified by the representative, or , in the presence of the representative, obtain a sample of the liquid latex admixture and cement being used in the mixture and deliver the samples to the representative for testing. The representative will submit the samples to LTS for testing. Circulate and mix latex tank as recommended by the latex manufacturer.

3. **Placing and Finishing Equipment**. Provide finishing equipment as specified in Section 1001.3(k)6.c. Provide hand tools for placing and brushing-in freshly mixed latex and for distributing latex over the bridge deck surface before striking off with the mechanical finishing equipment. Use approved hand-operated vibrators and screeds to place and finish small areas of work. Do not use two cycle engine vibrators or equipment on the prepared deck. Conduct final finishing operations immediately behind the finishing machines or screeds from work bridges of rigid construction, not in contact with the surface of the concrete, set on rails, and easily moved.

(b) Surface Preparation. Before scarification, hydrodemolition, or removal of portions of the deck surface, survey existing gutterlines and breakpoints every 25 feet, including each metal expansion dam along the length of the bridge deck.

Not more than 7 days before the placement of the overlay, scarify the deck surface, to the depth indicated, as specified in Section 1041.

When the indicated surface preparation includes scarification without hydrodemolition, perform scarification, then remove remaining unsound concrete and repair as specified in Section 1040.

When the indicated surface preparation includes scarification and hydrodemolition, perform hydrodemolition after scarification to provide a rough and bondable surface and to remove unsound concrete, as specified in Section 1039. Perform Type 3 concrete bridge deck repairs after hydrodemolition, as directed and as specified in Section 1040.

Before placement of the latex overlay, complete Type 3 deck repairs and Type 2 deck repairs exceeding 4 inches in depth as specified in Section 1040. Type 2 deck repairs that do not exceed 4 inches in depth can be placed concurrently with the latex overlay.

Abrasive blast exposed reinforcement bars to remove rust, contaminants, and pockets of corrosion. Do not apply epoxy coating to reinforcement bars.

Not more than 24 hours before placement begins, clean the entire surface, including edges of previously placed lanes of latex, to remove trowel-cut surfaces and promote bond. Clean the surface thoroughly by water blasting, and air blasting using clean, oil-free compressed air to remove dust, slurry, blast media, weak or fractured concrete, petroleum stains, leaves, paint, debris, oil, or other foreign materials detrimental to achieving bond, if necessary. Protect the entire prepared deck surface against contamination by covering with clean, full-width polyethylene sheeting until the overlay operations are completed. Include cleaning methods in the QC Plan, as specified in Section 1042.3(c).

Allow 48 hours of curing to elapse before performing scarification, hydrodemolition, or chipping on adjacent concrete within 6 feet of previously placed latex.

Raise expansion dams and scuppers if indicated before placing the wearing surface.

(c) Placing and Finishing.

1. **Quality Control (QC) Plan**. Prepare and submit a field operation QC Plan for review and acceptance according to Form CS-1042. Do not proceed with latex placement until the QC Plan has been accepted. Include in the QC Plan, testing and sampling frequencies and target points to initiate corrective measures. Include key personnel and relevant experience, method of operations, a sketch describing the equipment, and showing complete details of supports for the equipment.

2. **Pre-latex Placement Meeting**. At least 2 weeks before overlay placement, schedule a pre-latex placement meeting to review the specification, method and sequence of placing latex, quality control testing, and method of protective measures to control the concrete evaporation rate.

3. **Fi**nishing E**quipment**. Provide anchorage for supporting rails for horizontal and vertical stability. Do not treat screed rails with parting compound to facilitate their removal.

   Adjust screeds to finished grade before placing the wearing surface. For super elevated bridges, adjust screed guides to compensate for the curvature.

   Determine the finished grade by referencing the survey data obtained before surface preparation. Raise the existing grade or match existing grade, as indicated. Provide a final setting of the screeds such that a smooth riding surface is achieved. Do not lower the screed to compensate for wear on the existing deck or for over scarification or hydrodemolition. Before placing latex, perform a dry run by passing the finishing equipment over the deck area to check the clearance between the bottom of the screed and the prepared surface. Demonstrate that the fogging equipment is working properly during the dry run. Remove concrete that does not clear the screed by the minimum depth of wearing surface.

4. **Latex Placement and Finishing**. Immediately before placement of the latex, thoroughly wet the clean surface for a period of not less than one hour. Vacuum standing water in depressions, holes, or areas of concrete removal. Maintain prepared deck in a damp, puddle-free condition. Use a fogger/mister to dampen visible dry spots before the latex placement.

   Brush/broom damp vertical surfaces with latex grout. For horizontal surfaces not prepared with hydrodemolition that will be in contact with the latex overlay, brush/broom damp horizontal surfaces with latex grout. When using latex concrete, collect and discard excess aggregate. Do not over-extract grout from the mix to the point that the grout becomes diluted. If directed, apply a second brushed/broomed coat of grout to areas where grout is diluted by excessive surface moisture. Immediately remove material from the deck that is not properly mixed or proportioned, or lacks component material, and regrout the area. Ensure brushed/broomed surfaces receive a thorough, even coating of latex grout and that the rate of progress is limited so that the brushed/broomed material does not become dry before it is covered with additional material, as required for the final grade.

   Place and strike-off the mixture to approximately one quarter inch above final grade. Vibrate latex in front of finishing machine. For hydrodemolitioned surfaces, snake vibrator through latex at no more than 12 inch passes. Vibrate edges adjacent to joint bulkheads and expansion dams, in depressions, and in areas of bridge deck repair. Fill and consolidate each Type 2 deck repair placed concurrently with the overlay before the advancement of the overlay placement operation. Finish to final grade with the approved finishing equipment. Hand-finishing with a float may be required along the edge of the placement or on small areas of repair. Edge-tooling is required at joints, metal expansion dams, curbs, and previously placed lanes. Place latex continuously and complete the finishing of each area within 15 minutes after the initial brooming. Provide finish with a closed surface, free of pock marks, ridges, tears, and other defects. Place latex at a minimum rate of 20 linear feet of deck per hour, in a longitudinal direction.

When placing latex against latex that has not achieved initial set, but has formed a surface crust or film, remove the surface crust until plastic latex is exposed, place fresh latex against the exposed surface and consolidate both until homogeneous.

Separate screed rails and construction bulkheads from the newly placed material by passing a pointing trowel along their inside face. Do not separate metal expansion dams from the wearing surface. Ensure that this trowel cut is made for the entire depth and length of rails after the mixture has stiffened sufficiently.

Conduct operations behind the finishing machines or screeds from work bridges suspended above the wearing surface. Provide work bridges of rigid construction. Do not allow work bridges to come into contact with the surface of the latex.

Perform straightedge testing, surface correction, and edging while the latex is still workable as specified in Section 501.3(k)3. After the straightedge testing and surface corrections have been completed and before the latex becomes nonplastic, manually texture/tine the surface as specified in Section 501.3(k)4 if mechanical texturing is not indicated. Cure the wearing surface as soon as possible without marking the fresh latex. After the latex has hardened, test the surface again as specified in Section 501.3(o). Resound the deck if directed.

When mechanical texturing is indicated, perform as specified in Section 1001.3(k)6.f. Do not begin grooving operations until directed, the latex has reached a compressive strength of 3,000 psi according to PTM No.604, the grooving equipment live loads can be applied as specified in Section 1042.3(g), and until the surface tolerance has been checked and high points are removed as specified in Section 501.3(o).

Provide adequate lighting, as indicated on the field operation QC Plan, for placement not completed in the daylight. Ensure lighting allows proper placement, testing, and inspection operations of the entire surface area and until curing covers are placed over the surface area.

(d) Curing and Protection. Begin curing as soon as the latex has been placed, finished, and textured, if applicable. Do not use membrane-forming or monomolecular curing compounds:

1. **Curing Temperatures, Curing Days and Records of Temperature**. Sections 1001.3(p)1 and as follows: Maintain cure temperatures of 45°F or greater throughout the wet and dry cure period. Do not count as a curing day a day on which the curing temperature drops below 45°F. If the curing temperature falls below 35°F during the curing period, the department will consider the work unsatisfactory and it will be rejected. Protect the overlay using methods as specified in Section 1001.3(p)4 during cool weather and Section 1001.3(p)5 during cold weather.

2. **Water Cure**. Saturate curing covers before use and keep in a saturated condition for the curing period. Soak burlap for a minimum of 48 hours before placement. Re-wet burlap as needed before placement. Promptly cover the surface with a double layer of clean, wet burlap within 15 feet of strike off from the finishing machine. Place burlap so each strip overlaps one half its width. Minimal marking of the surface from curing covers is allowed. Maintain burlap in a fully wet condition using misting hoses, fogging machines that span the entire burlap-covered surface, or other approved devices until the concrete has set sufficiently to support foot traffic. At that time, place soaker hoses on the burlap to maintain continuous saturation of burlap over the entire deck surface. At a minimum, place soaker hoses at grade breaks and high sides of super elevations to ensure continuous saturation. Secure burlap to prevent lifting or displacement due to adjacent construction operations or wind. Cure the surface according to Table A.

3. **Dry Cure**. After water curing, remove the curing covers and dry cure for an additional period according to Table A. Maintain the surface of the overlay in a dry condition for the entire dry cure period. Cover the surface with waterproof coverings as required. If the overlay surface becomes wet during the dry period, extend the dry cure period to the equivalent time that the overlay surface was wet.

TABLE A Curing Times and Application of Live Load

Overlay Type	Depth	Water Cure (hours)	Dry Cure (hours)	Live Load Application Total Cure Time MIN (hours)	Live Load Application Comp. Strength MIN (psi)
LMM or LMC	≤ 2 inches	48	72	120	3,000
	> 2 inches	48	96	144	3,000
Accelerated LMC, 3 Hour	All	3	None	3	3,000
Accelerated LMC, 12 Hour	All	12	None	12	3,000

(e) **Limitations of Operations**. Place the latex during periods where the ambient and substrate deck temperatures are between 45°F and 85°F. At ambient temperatures above 80°F, conduct the overlay placement at night or during the early morning hours. If the ambient temperature is expected to reach 80°F 24 hours before the overlay placement, take steps necessary, but not limited to, the following to mitigate the mix component temperatures that are acceptable to the representative:

- Cover the latex admixture tanker and cement tanker with wet burlap or station the latex admixture tanker and cement tanker in shaded areas.
- Condition aggregates with cool water, cover with light-colored tarps, and/or stockpile in shaded areas.
- Charge the water tank on the mobile mixer with cool water as close to the time of placement as possible or condition with ice.
- Park mobile mixes in shaded areas or cover with wet burlap before the placement.

Place latex at a plastic latex mixture temperature between 50°F and 85°F. Stop the placement if the representative determines that a satisfactory surface finish is not being achieved.

Install a bulkhead in case of a major delay in the placement operation resulting in the formation of a surface film.

During minor delays, protect the placement from drying with several layers of wet burlap.

Take adequate precautions to protect freshly placed latex from rain. Stop placement operations when it starts to rain. The representative may order removal of latex damaged by rainfall.

Do not place latex when the evaporation rate exceeds 0.06 pound per square foot per hour according to ACI 305R, Figure 2.1.5. Wind breaks, sunshades, or fogging may be used to reduce evaporation to below the maximum allowable rate.

Discontinue placement when the representative determines that flash set of the latex does not provide a suitable placement or finish. Submit redesign and corrective action plan as directed.

(f) Testing and Acceptance.

1. Concrete Field Testing Technician. Section 704.1(d)2.a

2. Testing Facilities and Equipment. Section 704.1(d)3

3. QC and Acceptance Testing.

3.a QC Sampling and Testing of Plastic Latex. Perform testing according to the accepted QC Plan. Furnish a copy of the QC Plan to be maintained in the department's field office.

Test each 5 cubic yards of latex for plastic air content, temperature, and slump. Continue testing the load until control is established. Do not wait for the completion of the initial test before collecting subsequent samples. Perform slump tests as specified in Section 1042.2(f) and air content tests according to AASHTO T 152. Notify the inspector when sampling and QC testing are to be performed. The inspector will witness the sampling and QC testing. Report test results to the inspector promptly. Coordinate and facilitate changes as needed in a timely manner.

Do not incorporate latex into the work that does not conform to specification requirements.

Immediately separate and remove nonconforming material from the deck surface.

3.b Acceptance Testing. Latex will be accepted on a lot-by-lot basis. Test for plastic air content according to AASHTO T 152; temperature; and compressive strength according to PTM No. 611 and PTM No. 604. Each lot will consist of 20 cubic yards or a day's placement, whichever is less.

The inspector will select acceptance samples (n=1) according to PTM No. 1. Obtain samples of fresh latex at the point of placement under the direction and supervision of the inspector and according to PTM No. 601. Acceptance testing of plastic concrete will be performed at a site near the point of placement, as selected by the inspector. Latex will be tested for yield as directed. Latex not conforming to specification requirements at the point of placement will be rejected.

If the results of testing the plastic latex conform to specification requirements, mold a sufficient number of acceptance cylinders for five day compressive strength tests. Compressive strength cylinder molds of 4-inch diameter by 8-inch height may be substituted for cylinder molds of 6-inch diameter by 12-inch height. Perform compressive testing according to PTM No. 604. The inspector will identify the cylinders as acceptance cylinders. Field cure cylinders as specified in Section 1042.2(f). The compressive strength of the sample will be determined as the average of the compressive strength of two individual cylinders. The lot will be accepted when the five-day compressive strength meets or exceeds 3,000 pounds per square inch.

3.d Bond Tests.

3.d.1 Scarified Surfaces (no hydrodemolition). When the indicated surface preparation includes scarification without hydrodemolition, perform a vertical pull bond test according to ASTM C1583 between 24 hours and 72 hours after curing is complete and the latex has attained a minimum compressive strength of 3,000 psi. Perform a minimum of one vertical pull bond test on each span or day's placement, whichever is smaller, at a location or locations as designated. If multiple tests are taken in a span, the test result is the average of the tests for that span. The required minimum bond strength between the latex overlay and substrate is 250 psi. If the initial vertical pull bond test results do not meet the minimum requirement of 250 psi, perform up to three additional vertical pull bond tests per span where the minimum requirement of 250 psi was not met. After additional testing, if the average of the test results for a span do not meet the minimum requirement of 250 psi, the bond between the substrate and latex overlay in each span not meeting this requirement is considered defective work, and the latex overlay must be removed and replaced at no additional cost to the department. Repair bond test locations with nonshrink grout, as specified in 1001.2(d).

3.c.2 Hydrodemolitioned Surfaces. When the indicated surface preparation includes hydrodemolition and the overlay exhibits cracking or surface tears and potential debonding, perform bond tests as specified in Section 1042.3(f)3.c.1 as directed.

(g) Application of Live Loads. After latex placement, do not allow heavy equipment or vehicular traffic on the latex surface until the end of the period according to Table A, and until the latex has achieved the minimum strength specified in Section 1042.3(d), Table A.

(h) Defective Work. Sections 105.12 and 1001.3(u), and as follows:

When latex overlays exhibit cracking or surface tears, perform an investigation with the representative to determine the type of cracking, source of cracking, and extent of cracking. Measure the width, depth, and length of each crack and establish the locations of the ends of each crack with respect to permanent reference points. Coring may be necessary if crack depths cannot be accurately determined using a mechanical probe. If coring is required, obtain two cores at each location, submit one core to an independent laboratory for analysis of the cracks, and submit one core to the representative for analysis of the cracks at the LTS.

If the investigation indicates the type of cracking to be nonstructural cracks (plastic shrinkage, drying shrinkage, temperature related, or surface tears caused by finishing and texturing) that are evidence of defects in materials or workmanship, repair surface cracks and tears greater than ¼ inch depth and between 0.007 inch and 0.016 inch width at no additional cost to the department. Use a high-molecular-weight methacrylate penetrating crack sealer, a low-viscosity epoxy resin, or other suitable material to repair the surface cracks and tears.

Submit for review a detailed Quality Control and Action Plan that includes, at a minimum, the proposed crack-sealing material data sheet from the manufacturer and conditions for use, including ambient and substrate temperature and moisture conditions. Do not perform crack sealing before the Quality Control and Action Plan has been reviewed by the representative.

Keep cracks clean, covered, and dry until the crack-sealing operation is performed to the satisfaction of the representative.

Unless directed in writing by the district executive, remove and replace wearing surface deficient in surface tolerance as specified in Section 501.3(o); defective in air content as specified in Section 1042.2(f); defective in compressive strength as specified in Section 1042.3(f)3.b; failing to bond to the substrate; bonded to unsound concrete; exhibiting nonstructural cracks or tears greater than one-quarter inch depth and greater than 0.016 inch width; or showing surface defects resulting from the effects of rain, improper finish, improper cure, or honeycombing, which, in the representative's opinion, cannot be repaired.

1042.4 MEASUREMENT AND PAYMENT—

(a) Latex Modified Mortar or Concrete Wearing Surface. Square yard as indicated, for the type specified, for the item indicated.

Survey prior to surface preparation and bond tests are incidental to this item.

The department will pay for grade adjustments of expansion dams and scuppers, scarification, and hydrodemolition separately.

When hydrodemolition is not indicated, the department will pay for bridge deck repairs separately under the respective type of concrete bridge deck repair items.

When hydrodemolition is indicated, the department will pay for Type 3 deck repairs and Type 2 deck repairs exceeding 4 inches placed and cured before the overlay placement.

Latex Modified Mortar or Concrete, Variable Depth. Cubic Yard

The limits of payment are the peaks of the roughened deck surface elevation to the bottom of the latex modified concrete wearing surface.

For material costs only for furnishing latex modified mortar or concrete to the work site. Labor and equipment costs to place the material are incidental to the latex modified concrete wearing surface work.

Excerpts from Structures Procedures – Design – Plans Presentation PDT – Pub No. 15M, December 2019 Edition, Pennsylvania Department of Transportation Design Manual Part 4[4]

DM-4, Chapter 5 - Rehabilitation Strategies April 2015

5.6.4 Concrete Deck Overlays

5.6.4.1 General

The three most commonly used concrete deck overlays in Pennsylvania are epoxy overlay, membrane waterproofing with bituminous overlay, and latex modified concrete overlay. The advantages and disadvantages of each are listed in PP5.6.4.2 through PP5.6.4.4.

Two decision trees for concrete deck overlay treatments (**Figure A-7** and **Figure A-8**) have been developed as guidelines to aid in the decision-making process for determining when a deck overlay should be placed, what type of overlay should be placed, and the expected life cycle of the overlay. These guidelines were developed from survey results from all of the engineering districts within Pennsylvania. The goal of developing the guidelines is to establish a routine preventive maintenance cycle for concrete bridge decks. The functionality of the bridge and the overall plan for the highway corridor should be evaluated to determine if the existing bridge/concrete deck is a candidate for preservation.

The use of these guidelines is at the discretion of the district executive.

4 Structures Procedures – Design – Plans Presentation PDT – Pub No. 15M, December 2019 Edition, Pennsylvania Department of Transportation Design Manual Part 4, http://www.dot.state.pa.us/public/Bureaus/BOPD/Bridge/DM-4/2019-Edition/DM-4_2019.pdf

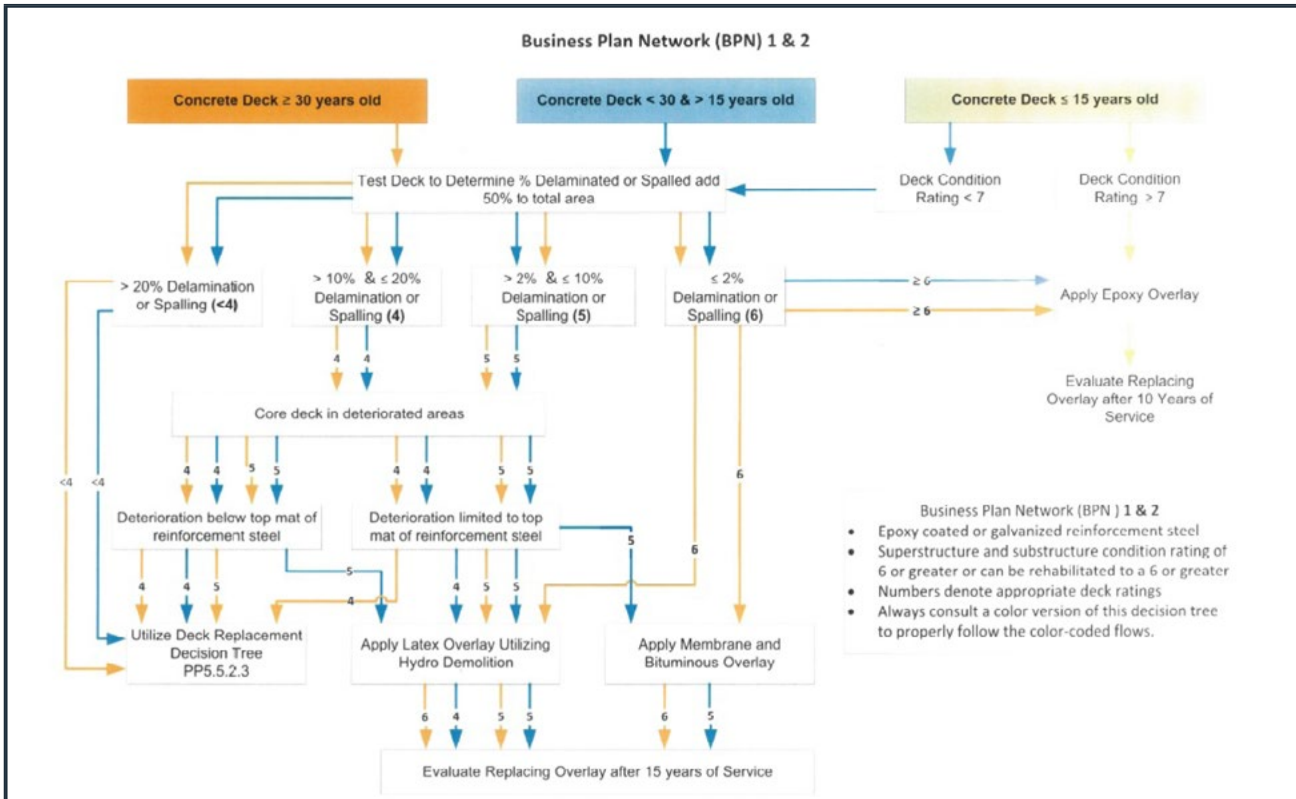

Figure 5.6.4.1-1 – Concrete Deck Overlay Decision Tree for Business Plan Network (BPN) 1 and 2

Figure A-7 Concrete deck overlay decision tree for business plan network 1 and 2 (Pennsylvania DOT)

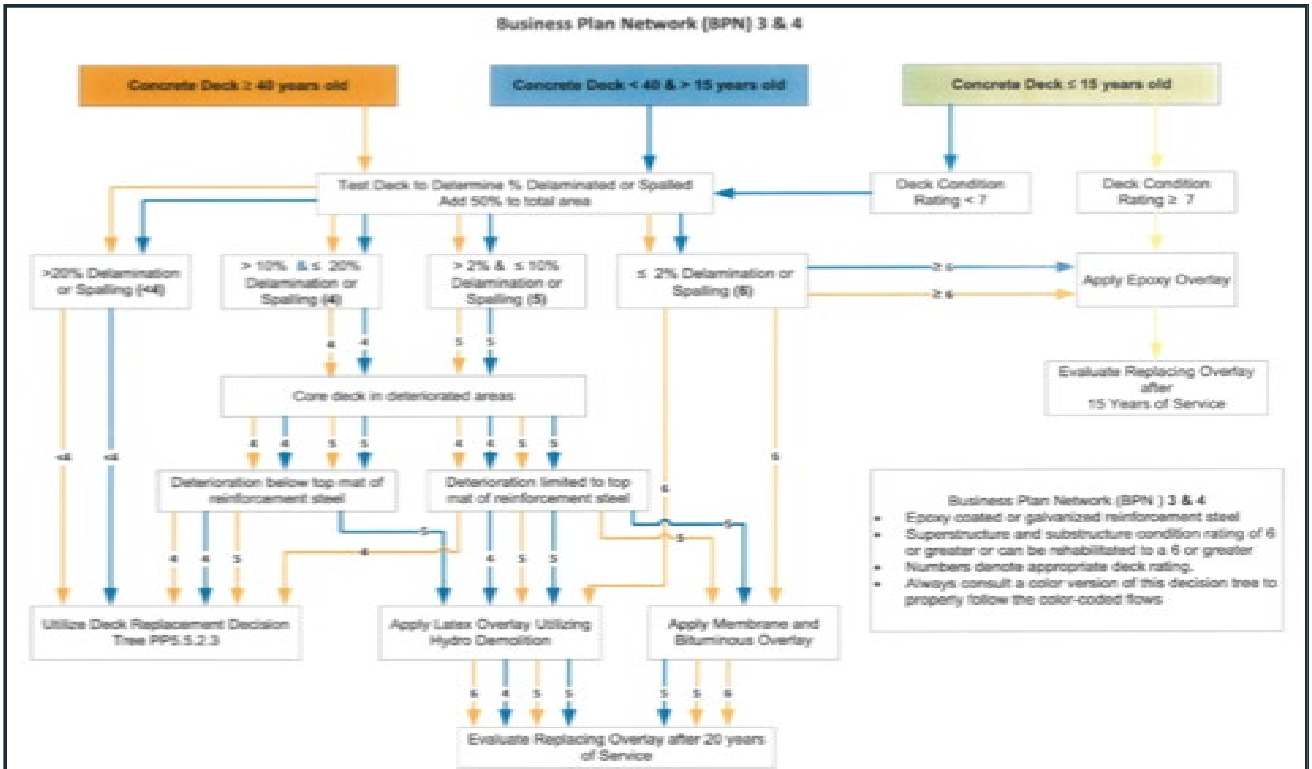

Figure 5.6.4.1-2 – Concrete Deck Overlay Decision Tree for Business Plan Network (BPN) 3 and 4

Figure A-8 Concrete deck overlay decision tree for business plan network 3 and 4 (Pennsylvania DOT)

5.6.4.2 Epoxy Overlay

An epoxy resin or epoxy urethane resin with a fine aggregate (angular silica sand, basalt, or highly siliceous metamorphic or igneous rock) wearing surface (epoxy overlay) has a minimum depth of 3/8 inch and an expected life between 10 and 20 years depending on traffic volumes and prior condition of bridge deck.

General Construction Operations

- Repair or patch areas of delaminated or spalled deck concrete
- Shot blast deck to obtain the required surface profile
- Clean deck to remove all dust and debris
- Deck must be dry
- Epoxy is placed on concrete deck and covered with aggregate
- A second layer of epoxy and aggregate is placed

Advantages

- Overlay can be applied during daylight traffic control operations
- Overlay may be opened to live traffic in a relatively short time frame
- Minimal addition of deadload added to the bridge
- Skid resistance is improved
- No profile adjustment required on approach roadway
- No modifications to existing deck expansion joints are required
- No modifications to existing deck scuppers or drains are required
- Lowest per-square-foot cost of all three overlay options
- Overlay can be patched or an overcoat application can be done
- Overlay can be placed over an existing latex overlay

Disadvantages

- Limited to decks in good condition such as small percentage of deck patches and hairline cracking
- Deck cleanliness is crucial to bonding of overlay
- Epoxy is temperature sensitive and must be applied in the correct temperature ranges
- Epoxy is sensitive to humidity and must be applied within the correct humidity levels
- Limited time duration between epoxy and aggregate placement
- Long-term performance in Pennsylvania is not known yet. (First application applied in 2004 and has performed well.)
- Problems with debonding on approach slabs have been encountered. Not recommended for approach slabs.

- Shorter life expectancy on higher volume roads than other overlay options. May require more applications than other overlays for the life of the concrete bridge deck.

5.6.4.3 Membrane Waterproofing with Bituminous Overlay

A membrane waterproofing system installed on a bridge deck and covered with a bituminous wearing surface has a minimum depth of 2½ inches (see Standard Drawing BC-788 for typical detail) and an expected overlay life between 10 and 25 years depending on traffic volumes and prior condition of bridge deck.

General Construction Operations

- Repair or patch areas of delaminated or spalled deck concrete
- Clean deck to remove all dust and debris
- Deck must be dry
- A layer of FJ-1 (sand-based wearing course) is applied to concrete deck surface, tack coat prior to paving
- A membrane waterproofing system is installed on top of FJ-1 layer
- A second layer of FJ-1 is applied
- A bituminous wearing surface is installed over FJ-1 layer

Advantages

- Overlay can be applied during daylight traffic control operations
- Overlay may be opened to live traffic in a relatively short time frame
- Skid resistance may be improved
- Overlay can be repaired or replaced
- Overlay system does not require a concrete deck with minimal delamination, cracking, or spalling
- No timing limitations between overlay placement operations
- May be placed on concrete approach slabs
- Depending on method of termination of overlay, leakage at abutments may be mitigated

Disadvantages

- Significant deadload added to bridge
- Profile adjustment required for approach roadway
- Concrete deck expansion joints will require an elevation adjustment, or a bituminous plug joint will be required over top of existing expansion joint
- Existing deck scuppers or drains will require an elevation adjustment

- Problems with membrane waterproofing system not sealing have been encountered and have led to trapping moisture between the concrete deck and bituminous wearing surface (drains through deck under membrane may be added)
- Shorter life expectancy on higher volume roads than other overlay options. May require more applications than other overlays for the life of the concrete bridge deck
- Bituminous pavement issues would apply to this system (e.g., shoving and rutting)

5.6.4.4 Latex Modified Concrete Overlay

A latex modified concrete (LMC) wearing surface has a minimum depth of 1¼ inch and an expected life between 15 and 25 years, depending on traffic volumes and prior condition of bridge deck.

General Construction Operations

- Scarify existing concrete deck surface and/or utilize hydrodemolition to remove a minimum of ½ inch from the concrete deck surface (ref Publication 408, Section 1041)
- Repair or patch areas of delaminated or spalled deck concrete; Type II repairs may be performed during LMC placement
- Place latex modified concrete wearing surface (Provide 2½ inches of minimum clear distance to top of steel reinforcement.)

Advantages

- Skid resistance may be improved
- Overlay can be replaced
- Generally the lowest cost per square yard per year of all three overlay systems
- Overlay system does not require a concrete deck with minimal delamination, cracking, or spalling if hydrodemolition is used
- Epoxy overlay can be applied to a latex overlay to prolong the life of the latex overlay

Disadvantages

- Overlay placement requires long-term traffic control operations
- Significant deadload added to bridge if overall deck thickness is increased
- Profile adjustment required for approach roadway
- Concrete deck expansion joints will require an elevation adjustment
- Existing deck scuppers or drains will require an elevation adjustment
- Problems with latex overlay cracking prematurely, which may require a sealer
- Problems with debonding of latex overlay; this problem can be minimized with the use of hydrodemolition rather than the use of scarification
- Requires an experienced contractor for placement

- Temperature sensitive during placement (high temperatures and flash setting concern)
- Limited time duration between mixing of modified latex concrete and placement

5.6.4.4.1 Latex Modified Concrete Overlays - Crack Criteria

Deck rehabilitation and preservation projects that utilize a latex modified concrete (LMC) overlay must have a precondition survey of the existing deck cracks, prior to the start of deck repairs and scarification/hydrodemolition, to locate potential flexural and reflective (structural) cracks in the LMC overlay.

Based on a report prepared by the Associated Pennsylvania Constructors (APC), dated March 2013, two types of cracking occur in LMC overlays. Nonstructural cracks (plastic shrinkage, drying shrinkage, surface tears, etc.) and structural cracks (e.g., flexural, reflective, and thermal). The report prepared by APC recommended that nonstructural cracks are to be repaired by the contractor, at no additional cost to the department, given these crack types are under the control of the LMC contractor. The report also recommended that structural cracks are to be repaired; however, the repair cost is the responsibility of the department, given that these crack types are beyond the control of the contractor.

Thermal structural cracks are defined in the report as having two (2) potential sources. The first potential source is the temperature difference (> 30 °F) between the curing LMC overlay and the underlying superstructure. The second potential source is the internal restraint at the ends of integral abutment bridges. The report recommends late evening LMC placements to avoid the cracking resulting from the differential expansion and contraction between the LMC overlay and existing superstructure.

Rehabilitation and preservation projects that require half-width construction of the LMC overlay may experience structural cracking of the LMC overlay due to adjacent truck traffic causing deflections in the superstructure during the curing period of the overlay. Thus, the contract documents shall have a pay item for epoxy injection crack repair in the event that these structural cracks occur.

Deck rehabilitation and preservation projects which utilize a "rapid set" latex modified concrete (LMC) overlay must include the "rapid set" stipulation on the drawing quantity tabulation.

5.7 PRESTRESSED CONCRETE BRIDGES

5.7.1 Repair of Prestressed Concrete Bridges

Department-sponsored research on prestressed concrete girder repairs can be found in FHWA Report PA-2009-008-PIT 006, "Repair Methods for Prestressed Concrete Girders"[5]. The department identified two repair methods that can be applied to the department's bridges from the numerous repairs investigated in the report. One of the selected repair methods will not restore beam capacity (repair of spalls and cracks) and one may restore beam capacity (damaged strands). The repair that will not restore beam capacity is the traditional concrete and mortar repair. The repair that may restore beam capacity is the non prestressed/post tensioned carbon fiber reinforced polymer (CFRP) repair.

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5 Repair Method for Prestressed Girder Bridges FINAL REPORT June 2009, 1. Report No. FHWA-PA-2009-008-PIT 006, Pennsylvania Department of Transportation, https://www.penndot.gov/ProjectAndPrograms/Planning/Research-And-Implementation/Documents/Repair%20Methods%20for%20Prestressed%20Girder%20Bridges.pdf

Repair and rehabilitation of damaged or deteriorated prestressed concrete beams, especially the repair of beams that were damaged by oversize vehicles is required on all rehabilitation projects.

The cause of the beam deterioration should be addressed to extend the design life of the repair. For example, leaky expansion joints must be repaired. A matter of concern is the observed deterioration of the bearing areas of some prestressed concrete box beams, generally found below leaky deck joints on structures usually more than 25 years old.

Spalling of the bearing areas is primarily caused by the infiltration of salt-laden runoff through leaky joints, with subsequent chloride saturation of the beam ends and resulting rusting of mild steel in the beam ends and, worse, rusting and debonding of prestressing strands.

Additionally, the beam seats at those deficient joints may be buried by 4 inches or more of salt laden cinders and other flushed roadway debris. Nothing will stand up under such an environment. Structures thus affected should receive priority treatment under the Bridge Preventive Maintenance Program.

As an initial measure, the bearing seats and beam ends should be flushed clean and the joints should be repaired (by installing strip seal joints or eliminating the joint by providing a continuous deck as part of a rehabilitation project).

The affected structures should be monitored regularly as part of the inspection process, and joints, particularly on prestressed concrete box beam structures, should be kept watertight.

Repair of Prestressed Concrete Bridges (Spalls and Cracks)

Refer to Standard Drawing BC-783M for Reinforced Concrete Repair Prestressed Concrete Beam [6] for repair details. A draft standard special provision for Prestressed Concrete Beam Repair has been developed and is under review.

If the repair area on the beam bottom flange at the bearing pad is greater than 10% of the bearing pad area, jack the superstructure off of the bearing pad during the construction of the repair. Jack and temporarily support the superstructure from the existing substructure, if possible, or construct a temporary support. Jack the entire end of the superstructure only the height required to insert a piece of galvanized sheet metal as a bond breaker for the new concrete repair.

6 Standard Reinforced Concrete Repair Bridge Decks, Drawing BC-783M, Pennsylvania Department of Transportation, http://www.dot.state.pa.us/public/Bureaus/BOPD/Bridge/2014/BC/bc783M.pdf

Case Study: Michigan DOT

Overview

The Michigan DOT (MDOT) comprises seven regions and a central office. MDOT has been performing hydrodemolition as part of the overlay process since the early 1990s and has used data collected over that time to optimize its procedures. MDOT has developed a set of bridge deck preservation matrices to assist the region bridge engineers in determining when a bridge deck overlay is appropriate and what kind of life expectancy can be anticipated from different solutions. MDOT regularly utilizes both deep and shallow overlays to extend the service life of its structures based upon condition ratings of the deck. This document will focus on utilizing hydrodemolition for deep concrete deck overlays.

Scoping, Planning, and Design

MDOT follows the federal requirements for routine safety inspections on all its structures throughout the state. Region bridge engineers utilize bridge safety inspection reports (BSIRs) to determine when work needs to be performed. When the bridge deck preservation matrices (**Figure A-9**) are used in conjunction with the BSIRs, AASHTO element data, work recommendations, and detailed bridge project scoping reports, these matrices can be an accurate guide in the majority of situations and will lead to a repair option that is economical and consistent with the department's goals.

BRIDGE DECK PRESERVATION MATRIX – DECKS WITH UNCOATED "BLACK" REBAR

DECK CONDITION STATE				REPAIR OPTIONS	POTENTIAL RESULT TO DECK BSIR		ANTICIPATED FIX LIFE
Top Surface		Bottom Surface					
BSIR #58a	Deficiencies % (a)	BSIR #58b	Deficiencies % (b)		Top Surface BSIR #58a	Bottom Surface BSIR #58b	
≥ 5	N/A	N/A	N/A	Hold (c) / Seal Cracks	No Change	No Change	N/A
				Silane			5 years
				Healer Sealer (d)			8 to 10 years
	≤ 10%	≥ 6	≤ 2%	Epoxy Overlay (f)	8, 9	No Change	15 to 20 years
	≤ 10%	≥ 4	≤ 25%	Deck Patch (e, j)	6, 7, 8	No Change	5 to 10 years
4 or 5	10% to 25%	≥ 5	≤ 10%	Deep Concrete Overlay (h, j)	8, 9	No Change	25 to 30 years
		4	10% to 25%	Shallow Concrete Overlay (h, i, j)	8, 9	No Change	20 to 25 years
				HMA Overlay with water-proofing membrane (f, i)	8, 9	No Change	8 to 10 years
		2 or 3	> 25%	HMA Cap (g, i)	8, 9	No Change	2 to 4 years
≤ 3	>25%	≥ 6	< 2%	Deep Concrete Overlay (h, j)	8, 9	No Change	20 to 25 years
		4 or 5	2% to 25%	Shallow Concrete Overlay (h, i, j)	8, 9	No Change	10 years
				HMA Overlay with water-proofing membrane (f, i)	8, 9	No Change	5 to 7 years
		2 or 3	>25%	HMA Cap (g, i)	8, 9	No Change	1 to 3 years
				Replacement with Epoxy Coated or Stainless Rebar Deck	9	9	60+ years

(a) Percent of deck surface area that is spalled, delaminated, or patched with temporary patch material. Top surface decision making based on concrete surface, not the condition of thin epoxy overlays or other wearing surfaces.
(b) Percent of deck underside area that is spalled, delaminated or map cracked.
(c) The "Hold" option implies that there is on-going maintenance to sustain current ratings.
(d) Seal cracks when cracks are easily visible and minimal map cracking. Apply healer sealer when crack density is too great to seal individually by hand. Sustains the current condition longer.
(e) Crack sealing must also be used to seal the perimeter of deck patches and joint replacements.
(f) Deck patching required prior to placement of epoxy overlay or waterproofing membrane.
(g) Hot Mix Asphalt cap without waterproofing membrane for ride quality improvement. Deck should be scheduled for replacement in the 5 year plan.
(h) If bridge crosses over traveled lanes and the deck contains slag aggregate, do deck replacement.
(i) When deck bottom surface is rated poor (or worse) and may have loose or delaminated concrete over traveled lanes, sidewalks or non-motorized paths, an in-depth inspection should be scheduled. Any loose or delaminated concrete should be scaled off and false decking should be placed over traveled lanes where there is potential for additional concrete to become loose.
(j) Some full depth repairs should be expected where top surface deficiencies align with bottom surface deficiencies.

Bridge Deck Preservation Matrix July, 2017 Rev.

Figure A-9 Bridge deck preservation matrix – decks with uncoated "black" rebar (Michigan DOT)

Construction

MDOT specifications utilize a combination of scarification and hydrodemolition to achieve the desired removal for a deep concrete overlay. The scarification has a minimum depth of one-quarter inch and a maximum depth of 1 inch above the top bar of the top mat of deck reinforcement. The contractor is required to use a pachometer or other department-approved methods to locate the depth of the reinforcement before performing scarification operations.

The hydrodemolition depth is determined using a calibration process. For deep overlays, after the scarification has been completed and the deck cleared of debris, the hydrodemolition equipment is placed in a 30-square-foot area of sound concrete. A series of trial pressures are run until the equipment can expose 75% of the top surface of the top bar. Then the hydrodemolition equipment is moved to an area of deteriorated or defective concrete and run at the same pressure as the successful trial to determine if the pressure is adequate to remove the unsound concrete.

After the hydrodemolition operation has made its first pass across the deck surface and the debris has been cleaned up, the substrate is sounded for areas that will require a second pass. The department permits the contractor to use manual pneumatic hammers (60-pound maximum) to remove the remaining unsound concrete in lieu of a second pass with the hydrodemolition equipment. Typically, all known full-depth repairs and any “blow throughs” from the hydrodemolition process are chipped out and formed during the second pass removal. MDOT standard specifications cover procedures and payment methods for this work. All areas of exposed and debonded reinforcement steel are also chipped three-quarters of an inch all the way around the steel to allow for proper bond and consolidation of the overlay concrete.

Water runoff and pH control from the hydrodemolition process are covered by special provision. As part of the specification, the contractor is required to submit a plan for controlling, handling, testing, treating, and disposing of the runoff.

MDOT standard specifications allow for the contractor to choose between a latex modified concrete (LMC) or a silica fume modified concrete (SFMC) for the concrete overlay and addresses the unique curing system required for each material. SFMC requires an active fogging system during placement and a seven-day wet cure, while LMC uses a two-day wet cure and a two-day dry cure. The most common overlay material is SFMC due to its economic, production, and transportation advantages. The department has also utilized a ternary blended concrete (silica fume/slag cement/Type I) and slag cement supplemented mix designs through special provisions. The department allows all these materials to be placed in patches and expansion joints monolithically with the overlay.

For safety, the department specifies the use of false decking and traffic shifts during hydrodemolition.

To assist with hydrodemolition and concrete overlay projects the department has developed inspection checklists, example runoff control plans, and pH control plan checklists to go with the standard specifications, special provisions, and standard details.

Example Project

- Project IM 41025-117335, 128601 & 129949
- Federal Project 1800115 & 1800117
- Location
  - I-96 over the Grand River and I-96 over the Marquette Railroad and West River Drive at the US-131 Interchange
  - Kent County Michigan, City of Grand Rapids
  - Structures B01-3, B01-4, R04-3 & R04-4

Description

R04-3 and R04-4 Over the Marquette Railroad and West River Drive

This project consisted of two six-span steel-girder structures, each being 544 feet, 3¼ inches long, with a 33-foot clear roadway, placed on a 37 degree, 7-foot 30-inch skew (**Figure A-10**). The bridges both had previous deep latex overlays and multiple patches. The original proposed project work for R04-3 and R04-4 included deck joint replacement and deck patching. MDOT's first step on a project like this is identification of patch locations. However, once the layout was completed and the patching quantity was calculated, it was determined that approximately 20% of the deck surface needed replacement; therefore, the scope of the project was changed to a deep SFMC overlay. This upgrade also increased the projected service life to match the remaining structures within the US-131 interchange.

Figure A-10 Structures over the Marquette Railroad and West River Drive (Michigan DOT)

B01-3 and B01-4, I-96 Over the Grand River

This project consisted of two six-span steel-girder structures, each 768-foot, 7 inches long over the Grand River, with a 32-foot, four-inch clear roadway, placed on a 22 degree 0-foot, 0-inch skew (**Figure A-11**). Both bridges previously had shallow latex overlays performed and had multiple patches. The project plans called for hydrodemolition with a deep overlay, and Concrete Grade D (7 Sack) was specified. Due to the cross slope of the existing deck, the depth of the overlay was changed to a variable depth in the field to correct the cross slope to provide drainage and safety. The overlay was changed to SFMC to increase bond strength and accommodate the adjusted overlay thickness. This project was over a waterway; however, due to previous communications between MDOT and the Michigan Department of Environment, Great Lakes, and Energy, wastewater treatment plans were not an issue as they had already been established.

Figure A-11 I-96 structures over Grand River at the US-131 interchange (Michigan DOT)

Project-Specific Challenges

Due to the structure lengths and physical barriers beneath the bridges, including railroad right of way, various physical barriers (i.e., ditches, vegetation, and boggy soil), and the Grand River, getting concrete from the trucks to where it was needed on the deck was a challenge. For the bridges over the Grand River, construction was staged part-width to accommodate concrete delivery (**Figure A-12**). In the case of the structures over the Marquette Railroad, the department partnered with the contractor to develop a plan to pad the area between and on top of the reinforcement steel, and place road plates to deliver concrete to the placement location.

Figure A-12 I-96 over the Grand River staged construction to accommodate construction loads (Michigan DOT)

There was some variability to the depth of existing reinforcement in the original decks. The specifications at the time gave minimum scarification depths but did not specify maximum depths. To minimize conflicts with the existing reinforcing steel by the milling operation, the contractor hand-chipped multiple locations throughout the decks to find steel cover prior to milling.

After first pass hydrodemolition, some areas of reinforcing steel were exposed that had unbonded with sound concrete around it (**Figure A-13**). These exposed bars were then all sounded to ensure a solid bond with the concrete substrate. Bars that were not uniformly bonded were fully exposed by hand-chipping to three-quarters of an inch below steel to accommodate bonding with the silica fume overlay.

Figure A-13 Marked reinforcing steel showing bars that have unbonded with surrounding concrete (Michigan DOT)

General Challenges

Depending on when bridges were constructed, MDOT has encountered multiple different standards for cross slope and drainage which were used at the time. Occasionally the cross slopes need to be corrected during the project to accommodate current drainage and safety standards. This sometimes requires a variable thickness overlay, and in some cases, a review of structural capacity if weight is being added during the overlay.

Over the years, restrictions to scarification depths have been adjusted to balance substrate condition and economic benefits. Concrete removal through scarification is more economical than hydrodemolition. However, excessive scarification led to an increase in microcracking and "blow throughs." To clarify the needed balance, MDOT has upgraded its standards for scarification and hydrodemolition depths to remove questions during bidding and construction.

While it is easy to see varying conditions of concrete over the surface area of a deck, until steel reinforcement is exposed, it is difficult to determine if there has been debonding between concrete and the existing reinforcement. Over time, MDOT has learned that the exposed reinforcement needs to be evaluated at each location to ensure all debonded areas are addressed prior to placing an overlay.

Frequently because of the differing conditions of concrete throughout a deck, it becomes necessary to recalibrate the hydrodemolition equipment during the process, adjusting pressures and speeds to achieve proper removal depths.

Concluding Remarks

MDOT has been working with concrete overlays in conjunction with hydrodemolition for nearly three decades (**Figure A-14**). In that time the department has adjusted concrete mix designs, calibration methods, scarification depths, concrete placement techniques, and curing procedures. The department has seen the performance of deep overlays continue to trend upward as a result of this work. As it currently stands, deep overlays that have utilized hydrodemolition are demonstrating a "time to poor condition" projection of over 40 years. This means that when a deep overlay is maintained with the same preservation techniques used on new decks, they are nearly doubling their service life projection.

Figure A-13 Marked reinforcing steel showing bars that have unbonded with surrounding concrete (Michigan DOT)

Appendix B: Scan Team Contact Information

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Appendix C: Scan Team Biographic Sketches

CHERYL HERSH SIMMONS (AASHTO Chair) is chief structural engineer for the Utah Department of Transportation, where she previously served as the structures design manager. Prior to joining the agency in 2013, she spent over 23 years in the private sector, focusing on project delivery and construction as a designer, resident engineer, project manager, and design quality manager. Simmons is a native of Maryland and earned her bachelor's degree in civil engineering from Duke University and her master's degree in structural engineering from the University of Virginia.

JOHN A. BELCHER II is the statewide bridge construction engineer for the Michigan Department of Transportation. His position focuses on achieving statewide alignment, implementing new innovations, and providing field support to the department's construction offices on all aspects of bridge construction and rehabilitation. His position also coordinates and partners with industry groups, associations, contractors, and consultants in the development and improvement of current bridge design and construction specifications. He has been with the department for 19 years, which included eight and a half years serving as the statewide concrete construction engineer. Belcher is a civil engineering graduate from Tri-Sate University in Angola, IN, and a licensed professional engineer in Michigan.

XIAOHUA "HANNAH" CHENG is a bridge and structure engineer for New Jersey Department of Transportation (NJDOT). Her primary duties include development and update of policy, manuals, standards, and guidance for design, construction, and maintenance of State highway bridges and traffic structures, using the state-of-the-art technology and products. Her duties also include development of special design and construction criteria for major bridge projects, including extreme events and various rehabilitation criteria. She develops problem statements and oversees State research projects in various topics. Dr. Cheng is serving AASHTO COBS (Committee on Bridges and Structures) as a member representing New Jersey. She has served on several committees, task forces, and panels of AASHTO, TRB (Transportation Research Board), NCHRP (National Cooperative Highway Research Program), ASCE (American Society of Civil Engineers), and industry organizations. Before she joined NJDOT, she was a researcher specialized in fatigue of steel bridges and structures with ATLSS Research Center, Lehigh University and Public Works Research Institute (PWRI), Japan. Dr. Cheng graduated from Tsinghua University (China) with Bachelor's degree in Civil Engineering, and holds doctoral degree from Nagoya University (Japan) in Civil/Structural Engineering; She is registered Professional Engineer in Pennsylvania.

ZHENGZHENG "JENNY" FU received her master's degree in civil engineering from Purdue University in 1991 and her bachelor's degree in mechanical engineering from Huazhong University of Science and Technology of China in 1984. She has more than 30 years of engineering experience in bridge, structural, and mechanical designs. Fu is the state bridge design engineer and is responsible for bridge design-related activities in Louisiana Department of Transportation and Development. She is Louisiana's voting member in the AASHTO Committee on Bridges and Structures (COBS) and serves in three AASHTO COBS technical committees, including T-10 (Concrete), T-8 (Movable Bridges), and T-11 (Research). She is a member of the FHWA Long-Term Infrastructure Program Expert Task Group for Bridges.

ROMEO R. GARCIA is a bridge construction engineer with the construction management team in the Federal Highway Administration's Office of Preconstruction, Construction, and Pavements in Washington, DC. In this position, he leads the advancement of highway bridge construction activities with transportation agencies and private industry, which includes identifying and deploying leading practices and technologies associated with highway bridge construction (i.e., contracting mechanisms, scheduling, equipment, labor, materials, and quality). Garcia has worked with FHWA since 1975 in various states across the country, providing oversight of highway and bridge construction projects with a major emphasis on the quality of the completed product. He holds a bachelor's degree in civil engineering from the University of Minnesota and a master's degree in public administration from Rutgers University.

PAUL PILARSKI is the north regional bridge construction engineer for the Minnesota Metro District and is acting bridge scoping engineer. He has been serving as a regional bridge construction engineer for the Minnesota Department of Transportation since 2012. Prior to joining the agency in 2010, he worked as a bridge design consultant for eight years with WSP in Minneapolis and three years with HNTB in Bellevue, WA. His role interacts with bridge-specific customers, including bridge maintenance, bridge construction, bridge scoping, and bridge project delivery personnel. His primary interests are improved construction controls, accelerated bridge construction techniques, and cost-effective preservation scoping. Pilarski is a graduate of the University of Minnesota with both a master's degree in structural engineering and a bachelor's degree in civil engineering. He is a registered professional engineer in Minnesota and California and a licensed structural engineer in Illinois. In addition, he has completed NACE CP2 training and is responsible for research oversight on five research projects anchored in his interest areas.

BEHROOZ RAD is the bridge engineer with Infrastructure Project Management Delivery division at the District Department of Transportation. His primary duties include leading multi-disciplinary teams of engineers, construction managers, environmental specialists, etc from early stages of planning and preliminary design to completion of construction for several capital projects. Prior to his role at DDOT, Behrooz worked in private sector with focus on delivery of design and construction of several signature bridges in the Mid-Atlantic region. Behrooz holds a masters degree in structural engineering from Virginia Tech and is registered professional engineer in District of Columbia as well as Virginia.

DEWAYNE WILSON is the bridge asset management engineer for the Washington State Department of Transportation. His primary duties include supervision of the Asset Management Unit, which is tasked with identifying and prioritizing the preservation needs of the 3,300 state-owned bridges. He works with others in the agency's Bridge Office to identify initial scopes of work for the bridge preservation projects, including concrete bridge deck rehabilitations that may use hydromilling scarification. He has been with the agency for 36 years, having done bridge inspections and managing the department's Bridge Deck Rehabilitation Program. He has been in his current position for 15 years. Wilson holds a bachelor's degree in civil engineering and is a licensed professional engineering in the state of Washington

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Appendix E: Amplifying Questions

Amplifying Questions to Be Answered During State Presentation

General Information

- How many bridges are in your inventory?
- How many square feet of deck are in your inventory?
- How many square feet of hydrodemolition for partial depth bridge deck removal have you done?
- When was your first hydrodemolition project?
- Are your decisions to use hydrodemolition made centrally or regionally?
- What are the roadblocks to more widespread usage of hydrodemolition?
- Why did you start considering hydrodemolition?

Scoping/Planning

- When and how do you choose to use hydrodemolition?
- What applications have you used hydrodemolition for other than partial bridge deck removal?
- What depth of concrete removal do you assume for the bridge deck? How do you determine the estimated depth?
- After hydrodemolition removal, what material(s) do you use as replacement for the removed material?
  - Including the use of fast set materials
- Do you have a deck preservation matrix that includes decision making for hydrodemolition? If so, please provide.
- Environmental coordination and controls, issues, solutions, best practices for the containment and disposal of "wastewater" from hydrodemolition:
  - What are common locations for disposal of water?
  - What methods for water treatment are used and what are the performance metrics to define "treated"?
  - Have contractors recycled/reused wastewater? If so, how has this been accomplished?
  - What are your containment requirements for both debris and water:
    - On bridge?
    - Under bridge?

- What memorandums of understanding or other agreements are in place with appropriate state environmental agencies? Are statewide permits in place?
- How do you handle/control noise pollution?

- What are the structure types for which you allow hydrodemolition? Are there structure types for which you do not allow hydrodemolition? Why?
- What are the MOT constraints/limitations when performing partial depth deck removal using hydrodemolition? How does construction duration influence the MOT plan? (e.g., no hydrodemolition over live traffic or phasing)?
- What testing/evaluation of the bridge deck do you do prior to decision making and/or plan development?

Design (Plan, Specification, and Estimate Development)

- How do you handle structural capacity evaluations during hydrodemolition and post-construction?
- What is your procedure for estimation of cost process?
  - Including applicable bid items and how is this measured?
  - Including the difference in price between deep and shallow removal?
- Do you have requirements for the exposure of reinforcing steel?
- Do you scarify/mill before hydrodemolition and, if so, to what depth?
- How short a bridge is too short to economically do hydrodemolition?
- Do you have a standard specification or do you use a special provision? If so, please provide in advance.
- Do you provide any test/condition data with bid documents or in another manner?
- What do you do to ensure public safety during hydrodemolition operations (e.g., lane closures below or false decking)?
- Do you have limitations on time of year/temperatures when hydrodemolition may be used? If so, why do you have these limitations?
- Would you allow other removal processes as part of a VE proposal when hydrodemolition has been specified?

Construction

- Do you use hydrodemolition on the complete bridge or using phases? Why?
- Have you ever used/required two hydrodemolition setups on the same bridge?
- Do you require equipment redundancies of your contractors?
- What are your qualification requirements for those performing the hydrodemolition work?
- Do you have a prequalified list of contractors for hydrodemolition? If so, has this been successful?
- Do you require a test section before hydrodemolition begins on the deck?
- Do you require repair of damaged epoxy coating? If so, please describe.
- Do you specify a depth of removal or do you calibrate to a certain concrete quality removal? Please describe.
- What guidelines/guidance is provided for construction inspection?
- Do you allow nighttime hydrodemolition? Are there special requirements during night work?
- Do you require a specific pre-activity meeting before starting hydrodemolition?
- Are there any special bracing considerations given for supporting the deck overhang?
- Do you have any additional safety requirements in your specifications for contractor workers for hydrodemolition?

Performance

- What is the life of a deck repaired using hydrodemolition?
- Do you do any post-installation testing?
- Have you conducted any research on hydrodemolition? If so, please provide references.