MID-AMERICA
TRANSPORTATION CENTER

Report # MATC-ISU: 134

Final Report
WBS: 25 1121 0003 134

Methods for Removing Concrete Decks from Bridge Girders

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2014

A Coopertative Research Project sponsored by
U.S. Department of Tranportation-Research, Innovation and Technology Innovation Administration

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Methods for Removing Concrete Decks from Bridge Girders

Final Report
August 2014

BRIDGE ENGINEERING CENTER

IOWA STATE UNIVERSITY
Institute for Transportation

Sponsored by
Federal Highway Administration
Mid-America Transportation Center
Iowa Highway Research Board
(IHRB Project TR-647)
Iowa Department of Transportation
(InTrans Project 12-435)

The preparation of this report was financed in part through funds provided by the Iowa Department of Transportation through its "Second Revised Agreement for the Management of Research Conducted by Iowa State University for the Iowa Department of Transportation" and its amendments.

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.	
WBS: 25-1121-0003-134			
4. Title and Subtitle Methods for Removing Concrete Decks from Bridge Girders		**5. Report Date** August 2014	
		6. Performing Organization Code	
7. Author(s) Brent Phares, Jennifer Shane, Justin Dahlberg, and Hongtao Dang		**8. Performing Organization Report No.** InTrans Project 12-435	
9. Performing Organization Name and Address Bridge Engineering Center Iowa State University 2711 South Loop Drive, Suite 4700 Ames, IA 50010-8664		**10. Work Unit No. (TRAIS)**	
		11. Contract or Grant No.	
12. Sponsoring Organization Name and Address Iowa Highway Research Board, Iowa Department of Transportation, 800 Lincoln Way, Ames, IA 50010 Mid-America Transportation Center, 2200 Vine Street, PO Box 830851, Lincoln, NE 68583-085 U.S. DOT Research and Innovative Technology Administration (RITA) and Federal Highway Administration, 1200 New Jersey Avenue, SE, Washington, DC 20590		**13. Type of Report and Period Covered** Final Report	
		14. Sponsoring Agency Code IHRB and SPR Project TR-647 TRB RiP Project 33519	
15. Supplementary Notes Visit www.intrans.iastate.edu for color pdfs of this and other research reports.			
17. Key Words bridges—concrete—girders		**18. Distribution Statement** No restrictions.	
19. Security Classification (of this report) Unclassified.	**20. Security Classification (of this page)** Unclassified.	**21. No. of Pages** 69	**22. Price** NA

16. Abstract

With ever tightening budgets and limitations of demolition equipment, states are looking for cost-effective, reliable, and sustainable methods for removing concrete decks from bridges.

The goal of this research was to explore such methods. The research team conducted qualitative studies through a literature review, interviews, surveys, and workshops and performed small-scale trials and push-out tests (shear strength evaluations).

Interviews with bridge owners and contractors indicated that concrete deck replacement was more economical than replacing an entire superstructure under the assumption that the salvaged superstructure has adequate remaining service life and capacity. Surveys and workshops provided insight into advantages and disadvantages of deck removal methods, information that was used to guide testing. Small-scale trials explored three promising deck removal methods: hydrodemolition, chemical splitting, and peeling.

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

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the Iowa Highway Research Board,
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Preparation of this report was financed in part
through funds provided by the Iowa Department of Transportation
through its Research Management Agreement with the
Institute for Transportation
(InTrans Project 12-435)

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ACKNOWLEDGMENTS

The research team would like to acknowledge the Iowa Highway Research Board (IHRB), Iowa Department of Transportation (DOT), Mid-America Transportation Center (MATC), and U. S. DOT Research and Innovative Technology Administration (RITA) for sponsoring this research. State planning and research (SPR) funding from the Federal Highway Administration (FHWA) was also used for this project.

EXECUTIVE SUMMARY

The infrastructure in the US transportation systems is at or beyond its current useful life (D'Agostino et al. 2007), and many deteriorated concrete bridge decks need to be replaced. Removing these decks without damaging the bridge superstructure is a tedious and expensive task that often controls the deck replacement timeline. With ever tightening budgets and limitations of demolition equipment, states are looking for cost-effective, reliable, and sustainable methods for removing concrete decks from bridges.

The goal of this research was to explore such methods. The research team conducted qualitative studies through a literature review, interviews, surveys, and workshops and performed small-scale trials and push-out tests (shear strength evaluations).

Interviews with bridge owners and contractors indicated that concrete deck replacement was more economical than replacing an entire superstructure under the assumption that the salvaged superstructure has adequate remaining service life and capacity. Surveys and workshops provided insight into advantages and disadvantages of deck removal methods, information that was used to guide testing. Small-scale trials explored three promising deck removal methods: hydrodemolition, chemical splitting, and peeling.

Hydrodemolition is suitable for both partial and full-depth concrete removal, but containing and treating the water is expensive. Chemical splitting did not sufficiently break the reinforcing concrete. Peeling seems to be effective, but additional testing is needed. Shear strength evaluations suggested that shear strength is not sensitive to the quantity of concrete removal and that it may not be necessary to remove all of the concrete around shear connectors.

1. INTRODUCTION

In a recent survey of owners conducted by the Fails Management Institute (FMI) and Construction Management Association of America (CMAA) for facility construction and maintenance, seven challenges were outlined. The first challenge was: "Aging infrastructure in nearly every market segment is at or beyond its current useful life. The highway, street, bridge, marine port, airport, inter-modal, rail, K-12 and higher education facilities, water, sewer/waste disposal, electric transmission, and electric/gas distribution markets represent trillions of dollars in necessary spending over the next 10-20 years to upgrade and replace those assets" (D'Agostino et al. 2007). According to the American Society of Civil Engineering (ASCE) 2013 report card for America's infrastructure, the average age of the nation's 607,380 bridges is 42 years, and the decks of one-third of these bridges need maintenance, repair, or replacement (ASCE 2013). This sequence of events is increasingly expensive. Although bridges are typically designed to last for 75 years (AWS 2012), bridge decks deteriorate at a faster rate (Flowers et al. 2010). In the past, this has often meant that entire bridges were replaced at great cost. However, full-depth replacement of bridge decks that can be performed without replacing the bridge superstructures and substructures is one way of extending service life.

1.1 Problem Statement

Bridges typical undergo major deck replacement after about 40 years of service life (Tadros et al. 1998). Much previous research has focused on the design and construction of new concrete decks (Bettigole et al. 1997, Tadros et al. 1998, and Holden et al. 2014), but less research has been conducted on methods for removing existing concrete decks. Current deck removal methods (e.g., saw cutting, jackhammering, and blasting) often damage the bridge superstructure. Sometimes a lack of information on the as-built condition increases the possibility of damaging existing superstructures thereby increasing the cost of deck replacement and delaying the construction progress. Also, noise, vibration, dust, and falling materials associated with traditional deck removal techniques are environmental and public safety concerns. Consequently, bridge owners and contractors need economic, efficient, and reliable methods for concrete deck removal that do not damage existing superstructures.

1.2 Research Goal and Objectives

The overall goal of this research is to identify more efficient and reliable methods for concrete deck removal that preserve bridge superstructures and substructures. The preserved structures, for this work, are assumed to have adequate strength and remaining life. The tasks completed to meet the project objectives are as follows:

- Review literature about removing concrete decks from concrete and steel girders. This literature review covers deck removal methods and equipment and steel girder damage and repair.
- Interview bridge owners and contractors to determine cost effective replacement alternatives.

- Survey state departments of transportation (DOTs) to assess their experience with deck removal methods and identify current deck removal practices.
- Conduct meetings with Iowa and Nebraska bridge owners and contractors to discuss deck removal methods from steel girders and concrete girders.
- Conduct small-scale trials on promising deck removal methods on steel girders.
- Evaluate the performance of various shear connectors with partial concrete removal.

1.3 Research Approach

This study involved a literature review, three interviews, two surveys, two workshops, and two experimental studies. The literature review presents information on the state-of-the-art and state-of-the practice for concrete deck removal, steel girder damage repair, and other pertinent information. The interviews with both bridge owners and contractors focused on identifying cost-effective bridge deck replacement methods. A nationwide survey of state DOTs was conducted to identify current deck removal practices. Both bridge owners and contractors were invited to two workshops to discuss the advantages and disadvantages of deck removal methods.

The research team conducted two experimental studies. Small-scale trials of three promising deck removal methods that were identified through the surveys and workshops—hydrodemolition, chemical splitting, and peeling—were conducted to evaluate their effectiveness. Push-out tests were conducted to evaluate the shear strength when only a portion of the concrete was removed from around shear connectors.

1.4 Significance of the Research

The results of this study address two of the United States Department of Transportation (U.S. DOT) strategic goals: state of good repair and environmental sustainability (U.S. DOT 2012). Successful implementation of cost-effective deck removal methods maintains a state of good repair of the US transportation system. Efficient deck removal methods enhance a timely bridge deck replacement and avoid undesirable public inconvenience, travel delay, and economic hardship. These methods can preserve the superstructure resulting in improving the environmental sustainability of the US transportation system.

1.5 Organization of the Report

Following this introduction chapter, this report is organized into six additional chapters. Chapter 2 reviews pertinent literature and provides background information important to this study. Chapter 3 presents the results of interviews that focused on the cost-effectiveness of bridge replacement methods. Chapter 4 describes and reports the results of two surveys and two workshops that focused on deck removal methods. Chapter 5 describes the small-scale trials of three deck removal methods. Chapter 6 documents the shear strength evaluation for partial concrete removal around shear connectors. Chapter 7 provides conclusions and recommendations based on this research.

2. BACKGROUND AND LITERATURE REVIEW

This chapter has two sections. The first section reviews eight deck removal methods. The second section discusses steel girder damage and repair.

2.1 Deck Removal Methods

Depending upon the project requirements, a bridge deck demolition might use one method or a combination of methods. Manning (1991) reported that sawing, drilling, use of rig-mounted percussive tools, splitting, crushers, water jet cutting, ball and crane, and blasting are methods used to completely remove concrete from bridges. Abudayyeh et al. (1998) stated that machine-mounted demolition attachments, hydrodemolition, blasting and miniblasting, sawing and cutting, splitting, jackhammers, and thermal demolition are demolition methods and equipment for full and partial removal of reinforced concrete. This section describes the deck removal methods—sawing, breaking, hydrodemolition, drilling, splitting, crushing, blasting, and peeling—that participants in a survey and workshops conducted as part of this research indicated were the most commonly used demolition methods. These are presented in the order from most to least frequently used methods.

2.1.1 Sawing

Saws are commonly used in bridge deck removal. Bridge decks are typically saw cut into manageable sections and then removed by an overhead crane or other vertical lift equipment. In general, there are two types of saws: the diamond blade saw and the diamond wire saw (Manning 1991).

Diamond blade saws are available in different sizes and with different blade types, operating speeds, cooling systems, and power sources. The blades are steel disks with diamond segments welded around the rims and can cost anywhere from \$100-\$1,500. The quality of the blade depends on the composition of the metal bond, type, size, and concentration of diamonds. Diamond blade saws can either be dry- or wet-cutting. Dry-cutting blades can operate at temperatures between 400° and 550° F (204° and 288° C) (Manning 1991). Wet-cutting saws operate at temperatures around 212° F (100° C) by using water to cool the blades and reduce dust (Manning 1991).

Diamond blade rims are either continuous, serrated, or segmented and the geometry determines the cutting characteristics. Continuous rim blades typically create the smoothest cuts while serrated blades provide smooth cuts and faster cutting speeds. Segmented blades result in the smoothest cuts and the fastest cutting speeds and a long blade life. The segmented blade is typically used in cutting concrete decks (Manning 1991).

Diamond wire saws are made of steel beads with electroplated diamonds that are strung on a wire rope (Abudayyeh et al. 1998). Diamond wires are typically mounted on a drive wheel, which can slide to maintain tension in the wire by using either hydraulic or electric power. Hydraulic power is generally preferred because it is more portable. The drive speed is adjustable and the drive direction is reversible. Diamond-wire saws operate by threading the wire through two small holes, which determine the cut angle and length. Diamond wire cutting usually uses water to cool and clean the wire rope. Typical production rates for wire saws, usually between 5 and 40 ft^2/h (0.5 to 4 m^2/h), depend on the type of wire used, the aggregate properties, and the amount of reinforcement (Hulick et al. 1989). However, the life of diamond wires is relatively short compared with saw blades.

Sawing is a relatively rapid removal method that can cut concrete at any angle with negligible vibration and no falling materials. Wet-cutting can further reduce the amount of dust and noise. Wet-cutting can also avoid overheat during cutting and, compared to dry-cutting, prolong the useful life of the saw blades or cutting wires. Other factors that determine the cutting speed and blade life are the hardness of the concrete aggregate and the amount of reinforcement (Johnston 1994). It is important to note that personnel training are essential for both the safety and economics of employing this method, due to the costs associated with replacing blades (Abudayyeh et al. 1998).

2.1.2 Breaking

A pneumatic breaker, also known as a jackhammer or a paving breaker, is a common tool used for bridge concrete removal (Vorster et al. 1992). This pneumatic breaker breaks concrete into small, manageable pieces that can be removed by a loader bucket or other small, mobile construction equipment. Breakers are available in both hand-held and machine-mounted types.

Pneumatic breakers are typically classified by weight and power source. Jackhammers, a typical hand-held breaker, are powered by an air compressor, electricity, or gasoline engines (Abudayyeh et al. 1998). The internal hammer is iteratively driven down and then returns to the original position via a spring. These repeated cycles create a percussive impact on the concrete that breaks it into small pieces. A whiphammer is a hydraulically operated hammer, truck mounted, and attached to the end of a heavily restrained leaf spring arm. This type of hammer produces up to 42 blows per minute with the normal operation producing 35-40 blows per minute (Manning 1991). Large hydraulic breakers are typically mounted on an excavator. They are powered by hydraulic power provided by the excavator resulting in a production rate that exceeds both the whiphammer and jackhammer.

The production rate of a hand-held breaker depends on the operator’s skill and the breaker’s weight. The typical hand-held hammer ranges in weight between 20-90 lbs (Manning 1991). A typical production rate for a 30 lb jackhammer operated on a horizontal surface is 1 ft^3/h (Manning 1991). In comparison, the production rate for a whiphammer ranges from 200-600 ft^3/h for a 6 in. thick deck.

Regardless of the specific piece of equipment used, breaking creates a significant amount of vibration, noise, falling materials, and dust. Using a hand-held hammer is both labor-intensive and time-consuming. Percussive hammers can create high-level damage to the girder remaining in place, if the operator does not exercise care. Typically, state highway agencies limit the power and weight of the breaker to reduce the risk of damage (Weyers et al. 1993).

2.1.3 Hydrodemolition

Hydrodemolition, also called water jetting, breaks concrete by using high-pressure water (Weyers et al. 1993). Both hand-held and machine-mounted hydrodemolition equipment are available. Hand-held equipment can shoot water at any angle. However, hand-held hydrodemolition has a very limited production rate and induces operator fatigue and places the operator at risk. Machine-mounted hydrodemolition can remove deteriorated concrete or reasonable depths of sound concrete by applying a combination of different water pressures, frequencies, lance angles, and nozzle types (Weyers et al. 1993).

Hydrodemolition equipment consists of a power unit and a demolishing unit. The power unit is comprised of a drive engine, a high-pressure pump, water filters, a water tank, and other accessory equipment (Vorster et al. 1992). This unit is typically housed in a large truck or a flatbed tractor-trailer. The demolishing unit is a wirelessly controlled robotic vehicle with an oscillating nozzle connected by a high-pressure flexible hose.

Abrasive water used in hydrodemolition is specifically for cutting the reinforcing steel in concrete (along with removing concrete as well). There are three types of abrasives typically used, including minerals, metals, and artificial. These abrasives are typically stored in a hopper and metered to the nozzle during water jetting.

The production rates estimated for a typical 4,000 psi concrete and 3 in. removal depth are between 10 and 25 ft^3/h for single-pump systems and from 20-35 ft^3/h for dual-pump systems (Vorster et al. 1992).

Hydrodemolition produces no dust or vibration. This method protects steel elements from damage (VanOcker et al. 2010). Track-mounted hydrodemolition equipment is safe, but the power units can be noisy unless muffled.

2.1.4 Drilling

Drilling is typically not a sole removal method but is very important to the success of other removal methods. Drilling is typically the first step of preparing a bridge deck for removal when other methods, such as splitting, blasting, or saw cutting, will be used to perform the bulk of the removal process (Manning 1991). The resulting holes can be used in various ways during bridge deck demolition. For example, drilling creates voids where splitting or blasting agents may be placed. Drilling can also be used to define cutting directions or to weaken a component. Stitch-drilling creates overlapping small holes around the perimeter of a specific area of concrete and removes concrete at any depth or angle (Chynoweth et al. 2001). However, this method is practical only when removing concrete more than 18 in. deep, uncommon in bridge work (Manning 1991).

A typical drill includes the drill bit, chuck, torque selection ring, side handle, on and off trigger, forward and reverse switch, and a grip. Smaller drills are electronically powered and larger drills are hydraulically or pneumatically powered. Most drills used in deck removal operations have core bits made with low carbon steel, high carbon steel, carbide, or brazing diamond segments on steel shanks. The steel bits are usually coated with black oxide, titanium nitride, titanium aluminum nitride, titanium carbon nitride, diamond powder, or zirconium nitride to extend the cutting life of the bits.

Drilling is reasonably quiet and relatively inexpensive and produces little vibration and dust. However, operators should be aware that drill bits might damage steel girder flanges or blowout the bottom of the deck.

2.1.5 Splitting

Splitting involves applying tension on a pre-defined path within the concrete to fragment it in a controlled way. Two primary types of splitting are mechanical splitting and chemical splitting. Before splitting can be applied, holes must be drilled to accommodate the mechanical splitting equipment or the chemical splitting agent. The diameters, depths, spacing of holes, also collectively called the hole pattern, are all critical to the effectiveness of any concrete splitting operation. Hole patterns control the break orientation and protect some areas from unintended damage.

Mechanical splitting means that the concrete is placed in tension by inserting a mechanical splitter in a predrilled hole. Mechanical splitters are usually hand-held tools powered by hydraulic pressure. The splitter consists of a steel wedge placed between two hardened steel feathers in the lower cylinder and a piston in the upper valve cylinder. When the piston is pressurized, it pushes the wedge forward and applies forces on the feathers and thus against the sides of the hole. These feathers can exert a force of 125-410 tons (Abudayyeh et al. 1998).

Chemical splitting creates pressure in holes by using expansive chemical agents. The main component in chemical splitting agents is calcium oxide, which expands to about three times its original volume when hydrated with water. During use, the chemical powder is mixed with cold water to form slurry, which is then placed into pre-drilled holes. As the slurry hydrates, it expands over a period of approximately 48 hours, first cracking the concrete and then causing the cracks to propagate and widen. Typical pressures of 3000 psi (20MPa) after 12 hours and 9000 psi (62MPa) after 48 hours have been reported (Manning 1991).

2.1.6 Crushing

Crushing basically applies opposing forces on both sides of the concrete element to cut the internal reinforcement and break the concrete simultaneously. Using this method, both materials can be recycled.

Crushing tools, typically a jaw-like attachment mounted on an excavator, can produce crushing forces that break both the concrete and reinforcing steel. Three types of jaws are available including concrete cracking jaws, shearing jaws, and pulverizing jaws (Manning 1991). Concrete cracking jaws are designed for removing large sections of concrete. Shear jaws are used in cutting both concrete and reinforcement. Pulverizers are used to separate concrete from reinforcing steel. During demolition, crushers can be either fixed or flexible in the snapping direction and can be articulated with a rotator to adjust the snapping directions (Manning 1991).

The crushing method is relatively rapid and has minimal vibration and noise. Falling materials and debris must be collected and removed. This method is difficult to use over beams and the concrete above the girders will still require hand removal.

2.1.7 Blasting

Blasting, placing explosives in a certain pattern of holes to fracture concrete in a controlled way, is sometimes used in bridge demolition. Explosives produce shock waves and expanding gases in pre-drilled holes to form and widen cracks and fracture the concrete (Manning 1991). The effectiveness of blasting is controlled by the hole pattern, size of the blasting charge, and concrete properties, such as thickness, strength, quality of the concrete, and location of reinforcement.

There are four major classes of explosive: dynamite; mixtures of ammonium nitrate and fuel oil (ANFO); slurries; and blends of ANFO and emulsions (Manning 1991). Nitroglycerin-based dynamites are available in a wide range of small- and medium-diameter cartridges of different lengths. Dynamite has good water resistance, and is relatively reliable and predictable. ANFO, a combination of ammonium and fuel oil, is very economical and effective for large projects. It is best suited to dry conditions, but wet-use is also possible. Slurries are water gels or emulsions formed by mixing explosive chemicals with water. Water gels are explosive chemicals dissolved in water, while emulsions are explosive chemicals surrounded by a fuel mixture of wax and oil in water. Both can be either sensitive or insensitive to initiation by different formulations. Slurries are available in small- and medium-diameter cartridges or in bulk form. Emulsions and ANFO blends, a mix of high-velocity explosives in various percentages, are formulated to achieve varying degrees of water resistance, oxygen balance, density, velocity, pressure, environmental impacts, and cost (Manning 1991).

Blasting is a rapid removal method for large areas, if achieved correctly. This method is more suitable for removing an entire bridge than for deck removal only. Handling explosives is inherently dangerous. Therefore, this requires significant expertise to control the site, and maintain the safety of workers and the general public (Chynoweth et al. 2001). Blasting creates significant noise, dust, vibration, and falling materials in a short time.

2.1.8 Peeling

Removing a concrete bridge deck by peeling off the concrete by applying vertical forces on the deck to break the concrete free from the girder is a relatively new deck removal method. The method uses an excavator, a slab crab, and machine mounted bucket attachments (Morcous et al. 2013). Individuals have expressed concern that peeling might weaken shear connectors, but there is no published literature supporting or refuting this concern.

Peeling is a relatively rapid removal method, but results in notable vibration, noise, dust, and falling materials. It has not been used in deck removal projects in Iowa. This method was investigated as part of the study reported here.

2.2 Steel Girder Damage Repair

Cuts, dents, and bends are typical steel girder damage types that are caused by deck removal operations. Cuts and dents are typically repaired by grinding. Bends can be repaired by heat-straightening. Carrato (2013) discussed welding repair on structural members and pointed out that methods for repairing cracks are applicable to repairing cuts. This section reviews methods for repairing damaged steel girders.

2.2.1 Grinding

Conventional grinding can be used to repair minor damage such as cuts, gouges, nicks, and dents that are typically less than 0.25 in. deep (NY DOT 2009). This repair method prevents cracks, particularly at the surfaces of flanges, by grinding sharp edges to smooth surfaces. Bhatt et al. (2012) provided a two-step repair procedure for shallow nicks and gouges in steel members: (1) grind out the defect and blend the edges of the defect into the surface of the surrounding material at a 1:12 maximum slope and (2) prime and paint the exposed surfaces. Alberta Transportation (2004) specified that nicks and gouges shall be removed by grinding provided that the repaired cross-sectional area is at least 98% of the original cross-section. This repair should be accomplished by fairing to the edge of the material with a 1:10 maximum slope. Grinding marks should be parallel to the rolling direction. Specific requirements for grinding are based on the location and depth of the damage. For example, damage at the negative moment region of a bridge girder has a higher potential for crack propagation and typically has more stringent repair requirements.

2.2.2 Welding

Welding corrects cuts and cracks in steel girders. This method typically requires specific welding procedures and certified welders to produce high quality welds (Carrato 2013).

A typical welding repair includes damage removal, edge preparation, root placement, weld passes, grinding welds to a smooth surface, and inspection of the completed weld (Carrato 2013). A specific welding repair procedure for full-depth cracks is outlined in, "Welded Repair of Cracks in Steel Bridge Members" (Gregory et al. 1989). Carrato (2013) reported that this procedure can also be used to repair cuts.

- The base metal was preheated to 150° F.
- The crack was cut out from one side by air carbon arc gouging to approximately half-plate thickness.
- The groove was cleaned by rotary disc grinding, completing the required groove radius of 0.375 in. and angle of 20°.
- After cooling, visual and magnetic particle testing were performed on the grove and groove edges.
- The base metal in the crack area was preheated to 250° F for welding.
- The root, intermediate and final weld passes were completed, with visual inspection performed upon completion of each pass.
- Slag inclusions were removed and weld underfill repaired.
- Weld reinforcement was ground flush with the base metal.
- The area was post-heated to 400° F for one hour and covered by 6.25 in. thick Owens-Corning Fiberglass R-19 insulation for slow cooling.
- This process was then repeated for the other side of the web.
- Ultrasonic testing was performed in compliance with American Welding Society (AWS) Bridge Welding code AWS D1.5-88. The tension member requirements were used.
- Unsatisfactory repairs were gouged out and re-welded. (Gregory et al. 1989)

New York DOT (2009) recommended that impact damage be repaired for any of the following:

(1) Any damage that extends less than 0.25 in. into the base metal of the structure may be repaired by grinding. The base metal shall be made smooth and flush and shall be faired-out to a slope no less than 1:10 by grinding;
(2) Dents and gouges greater than 0.25 in. deep shall be repaired by welding using the shielded metal arc welding (SMAW) process;
(3) If cracks are present at the impact locations, grind and remove cracks and then continue with the welding repair.

2.2.3 Other Repair Methods

Other repair methods (e.g., heat-straightening, strengthening, or replacing damaged structure members) are rarely used in deck removal projects, but deserve some mention here. Heat-straightening damaged steel is accomplished by gradually applying controlled heat in specific patterns on plastically deformed regions. The Federal Highway Administration (FHWA) Guide for Heating-Straightening of Damaged Steel Bridge Members (2013) covers these topics: (1) heat straightening basics; (2) assessing, planning, and conducting successful repairs; (3) the effects of heat straightening on the material properties of steel; (4) the heat straightening of flat plates; (5) the heat straightening rolled shapes; and (6) heat straightening repair of localized damage.

Strengthening restores structural functionality by retrofitting existing structures or adding new structural elements such as cover plates, post-tensioning systems, or carbon fiber reinforced polymer (CFRP) strips. Sectioning and replacing portions of damaged structures or replacing whole structure members can be used to repair severe damage.

3. INTERVIEWS ON COST-EFFECTIVE ALTERNATIVES

Concrete deck removals requiring very cautious operations are expensive and time consuming. Individuals have been known to be concerned with costs associated with carefully remove concrete decks because they fear that costs may exceed the costs to replace the entire superstructure or bridge. This is especially true when damage occurs, which results in construction delays and extra costs for repair that may result in cost overruns. This chapter describes three interviews conducted to seek information on cost-effective bridge replacement alternatives (e.g., deck, superstructure, or entire bridge replacements).

3.1 Methods

Researchers at Iowa State University conducted three semi-structured telephone interviews to explore the cost of bridge replacement alternatives from a Midwest DOT estimator and two bridge contractors. Each interview took approximately 1.5 hours. A questionnaire (Appendix B) was used to guide the interview process. The DOT estimator has more than 30 years of bridge engineering and cost estimating experience. One of the contractors has 24 years estimating experience, including a 10 year experience as chief estimator in Texas and has performed a number of bridge deck replacement projects using different deck removal methods. The other contractor is a project director and has 16 years of experience with approximately eight years in steel girder bridge projects in Arkansas.

3.2 Interview Findings

Three telephone interviews were conducted at the Institute for Transportation on October 15, 2013, November 19, 2013, and December 12, 2013. The interviews were structured to obtain information in three main topical areas: removal methods and damage, cost and duration, and salvage or replacement.

3.2.1 Removal Methods and Damage

The interview participants confirmed that sawing and jackhammering are common conventional methods for removing concrete decks from steel girders. These methods are used by both state DOTs and contractors. The typical procedure to remove the concrete between steel girders is sawing the deck into sections and then lifting these sections by cranes. The concrete on top of the steel girders is typically removed by a handheld jackhammer or with an impact hammer mounted on a backhoe.

The consequence of damage is generally not considered in cost estimating or decision-making by either the DOTs or contractors. Most DOTs require contractors to submit a demolition plan that meets their specifications and special provisions. Special provisions typically specify that the contractor is responsible for repairing any damage (e.g., dents, cuts) to the structure that is planned to remain in place. In most cases, the interviewees indicated that damage is typically minimal and requires only insignificant repairs. If unexpected damage does occur, the designer of record or the

DOT would be responsible to estimate the damage, recommend repair methods, and evaluate the condition of the resulting repair.

3.2.2 Cost and Duration

The Midwest DOT uses cost-based estimates for major items and historical pricing for minor items. Deck replacements are considered renovations that should not exceed 70% of the cost of the entire bridge replacement. For estimating purposes, contractors typically keep historical cost data for preparing new estimates. Estimates begin with the quantity takeoff, and then that quantity is converted to man hours by dividing by typical production rates. The required duration is then calculated by adding the total man hours. Meanwhile, equipment, operation costs, rental costs, and small tool supplies are considered in the estimate.

3.2.3 Salvage or Replacement

Salvaging steel girders is desirable when the girders have adequate remaining service life and capacity. Fortunately, most damage caused by deck removal methods and equipment is typically minimal and not a factor when considering to either just replace the deck or to replace the entire structure.

State DOTs typically decide whether to salvage or replace existing bridge decks or superstructures and dictate demolition work in contract terms and plans. In design-build projects, the contractor might decide to either salvage or replace steel girders. In other cases, such as public private partnerships, the contractor will own, maintain, and operate the project for more than 30 years. The contractor will perform a cost analysis to determine the most economical strategy.

4. SURVEYS AND WORKSHOPS ON CURRENT PRACTICE

Because there was limited literature available on current deck removal practices, the research team at Iowa State University conducted a survey and a workshop to investigate the state-of-the-art deck removal practices on steel girders. A parallel study of deck removal methods for concrete girders was undertaken at the University of Nebraska-Lincoln (UNL). The research team at UNL conducted a survey and a workshop for deck removal methods on concrete girders. These surveys and workshops were designed to determine methods that state DOTs currently accept and to develop ideas for methods worth further exploration.

4.1 Methods

A survey questionnaire (see appendix A) was sent to the 50 state DOTs to collect information on full-depth concrete deck removal methods from steel girders. This questionnaire focused on eight deck removal methods: sawing, use of percussive tools, hydrodemolition, drilling, crushing, splitting, ball and crane, and blasting. Evaluations of these methods were based on cost, duration, noise, safety, and damage to the superstructure. The survey questionnaire addressed four main topics:

- Available special provisions and allowed methods for concrete deck removal
- Relative cost, duration, noise, safety, and damage related to each method
- Typical repair methods of damage
- Innovative deck removal ideas

A workshop that focused on methods for removing concrete decks from steel girders was held at the Bridge Engineering Center at Iowa State University. Eighteen workshop participants (eight bridge owners, six contractors, and four researchers) identified and discussed currently used deck removal methods (e.g., sawing, drilling, splitting, crushing, and hydrodemolition). The strengths and weaknesses of each method were discussed at length with the goal of identifying methods that might be the most promising for future development and usage. For the most part, the opinions expressed by the workshop participants were very similar to those obtained from the literature review.

Methods for removing concrete decks from concrete girders were investigated via a survey conducted by the University of Nebraska–Lincoln. Also, researchers from the University of Nebraska–Lincoln held a workshop focused on the removal of decks from concrete girders. Thirty-six workshop participants discussed current practices and brainstormed new, innovative removal approaches.

4.2 Survey of State DOTs on Methods for Removing Concrete Decks from Steel Girders

The research team received 28 responses from 50 state DOTs—a 56% response rate. The following states responded:

Delaware	Florida	Georgia	Hawaii
Illinois	Kansas	Maine	Maryland
Michigan	Minnesota	Mississippi	Missouri
Nebraska	Nevada	New Hampshire	New Mexico
New York	North Dakota	Oklahoma	South Dakota
Tennessee	Texas	Utah	Vermont
Virginia	West Virginia	Wisconsin	Wyoming

4.2.1 Deck Removal Methods

Ten states reported that they have special provisions for full-depth concrete deck removal. For example, New York State DOT has a special specification for removing slabs from steel girders that requires saw cutting 6 in. outside of the edge of the beams and removing the rest of the slab over the beams by hydrodemolition. This special provision has only been used four times in the last 10 years. Tennessee DOT limits the maximum pneumatic hammer sizes to 90 lb for full-depth concrete removal except over beams and 60 lb for removal over beams. Most state DOTs require the submission of the deck removal plan outlining the methods to be used including descriptions of the proposed equipment for prior approval.

Respondent states indicated that the top three most commonly used deck removal methods are saw cutting, use of percussive tools, and hydrodemolition as shown in Figure 1.

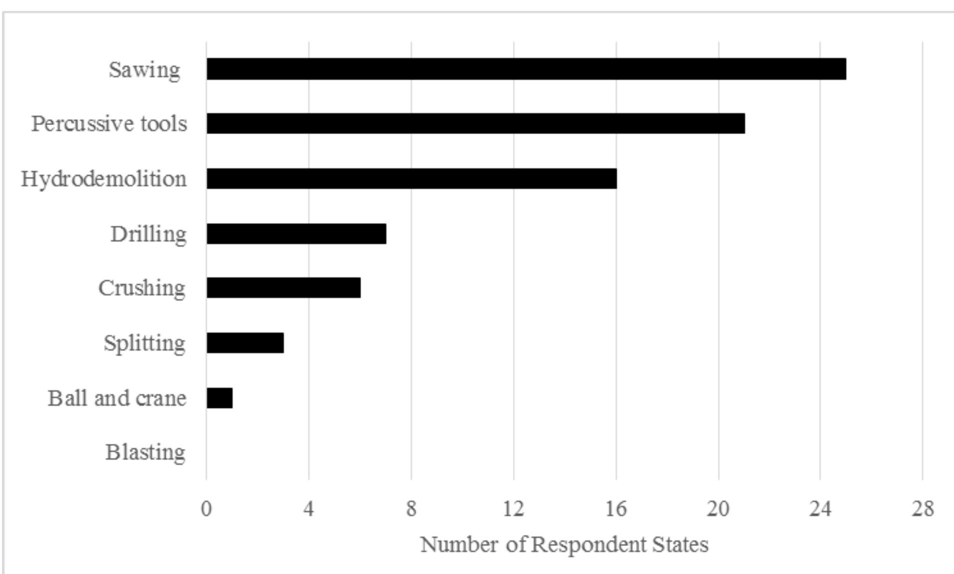

Figure 1. Currently allowed deck removal methods for steel I-girders

Missouri and Minnesota DOTs commented that sawing and the use of percussive tools are the primary methods used in their states. Mississippi and New Mexico DOTs indicated that they have successfully used hydrodemolition to remove deteriorated concrete for deck repair.

4.2.2 Relative Cost, Duration, Noise, Safety, and Damage

The relative cost, duration, noise, safety, and damage for sawing, use of percussive tools, and hydrodemolition are presented in Table 1.

Table 1. Survey results of relative cost, duration, noise, safety, and damage

Evaluation Criteria	Sawing	Percussive Tools	Hydrodemolition
Cost	Moderate	Moderate to Low	High
Duration	Moderate to Low	Moderate to Low	Moderate
Noise	Moderate	High	High
Safety	Moderate to High	Moderate to High	Moderate
Damage	Moderate	Moderate to High	Low

Sawing and use of percussive tools appear to be relatively cost-effective methods. However, these methods are noisy and may damage superstructure elements. Twelve states specifically indicated that sawing could damage the shear connectors. Four states reported rig-mounted percussive tools have a good chance of damaging the steel girders. Eighteen states reported that rig-mounted percussive tools could damage the shear connectors. Oklahoma DOT commented that saw cuts that extended into the top flanges of steel beams require expensive welding repair. A total of 19 states indicated that use of percussive tools is extremely noisy and sawing is moderately noisy. Hydrodemolition is expensive and noisy. Ten states indicated that hydrodemolition has no chance of damaging steel girders. New Mexico DOT suggested that hydrodemolition produced minimal damage to bridge girders when the water pressure was adjusted correctly. On the other hand, Tennessee DOT recommended hydrodemolition for only partial concrete deck removal.

4.2.3 Typical Repair Methods of Damage

According to the survey responses, actions taken to repair a damaged steel girder’s top flange depends on the level of damage. Small damage levels can be repaired by grinding or heat straightening. More significant damage tends to need welding, and severe damage requires full girder replacement. Most states require that contractors prepare a repair plan for approval in their bid document.

State DOTs were also asked about their experience with repair methods such as grinding, welding, heat-straightening, flange build-up, or replacing. Virginia DOT suggested grinding for nicks and gouges and full penetration groove welds for saw cut damage. Wyoming DOT recommended grinding, welding, and adding a cover plate for flange cuts depending on the cut depth.

4.3 Workshop on Methods for Removing Concrete Decks from Steel Girders

The previously mentioned workshop discussed and brainstormed the eight deck removal methods mentioned in the previously described survey. The workshop participants identified advantages and disadvantages associated with those removal methods and discussed innovative ideas and interest.

4.3.1 Sawing

Sawing is a relatively rapid removal method that can result in cuts at any angle with negligible vibration and no falling materials. This method generates little dust when wet-cutting is used. However, saw blades or cutting wires can possibly overheat during operation.

4.3.2 Breaking

Breaking (use of percussive tools) is relatively safe and rapid, but noisy, dusty and has significant associated vibration. This method requires a skilled, careful operator to avoid damaging structural elements left in place. Limiting the power and size of breaking equipment can also reduce the risk of damage.

4.3.3 Hydrodemolition

Hydrodemolition produces no dust. The pressure controlled cuts protect the steel beams and, when desired, the reinforcing steel from damage. However, the power units can be noisy unless muffled. Hand-held units induce operator fatigue and place the operator at risk.

4.3.4 Drilling

Drilling is typically combined with another method. It is reasonably quiet and relatively inexpensive. However, it was noted the drill bit might damage the steel girder flange or blowout the deck on the bottom.

4.3.5 Crushing

Crushing is relatively rapid, but produces noise, dust and vibrations. Falling materials are notable safety concerns. This method is difficult to use over beams and the concrete above girders will most likely still require hand removal.

4.3.6 Splitting

Splitting produces no vibration, little dust, and little noise. The remaining members are typically left undamaged. The splitting method is relatively safe and inexpensive for mechanical splitting. However, chemical splitting could be expensive.

4.3.7 Ball and Crane

The ball and crane method is relatively safe and rapid. However, the process is very dusty and noisy. This method has the least control and results in substantial vibrations.

4.3.8 Blasting

Blasting is a rapid removal method for large areas, if done correctly. This method is more suitable for removing an entire bridge than portion(s) of the bridge. Handling explosives is inherently dangerous, therefore, it requires significant expertise to control the site and maintain the safety of workers and the general public.

5. SMALL-SCALE TRIALS

Three deck removal methods—hydrodemolition, chemical splitting, and peeling—were selected for small-scale, controlled, laboratory trials based on the literature review and findings from the surveys and workshops. These methods have not been frequently used to remove bridge decks, but were thought to have the potential to change and positively impact the state-of-the-practice of deck removal practices.

5.1 Methods

The research team constructed three specimens for the hydrodemolition, chemical splitting, and peeling trials at the Iowa State University Structural Engineering Laboratory. Specimens were fabricated to simulate actual bridge deck conditions by using standard Iowa DOT C-4RW concrete mix (minimum compressive strength of 4500 psi or greater per Iowa DOT specifications). Grade 60 black reinforcing steel #6 bars were used at a typical 10 in. spacing for both the top and bottom layers of reinforcement. Materials, equipment, and testing procedures for each trial are documented in the following sections.

5.1.1 Hydrodemolition

A Midwest company specializing in hydrodemolition was invited to conduct the small-scale hydrodemolition trial at Iowa State University on October 17, 2013. The overall on-site time of this trial was approximately nine hours. The actual hydrodemolition time was approximately two hours.

5.1.1.1 Materials and equipment

The hydrodemolition specimen was a 20 ft long, 58 in. wide, and 8 in. thick reinforced concrete slab built on a 20 ft long, 10 in. wide and 0.25 in. thick steel plate. Two shear studs were installed 4 in. apart at a typical 10 in. spacing on the steel plate. A plan view and a cross-section view of the hydrodemolition specimen are shown in Figure 2 and Figure 3, respectively.

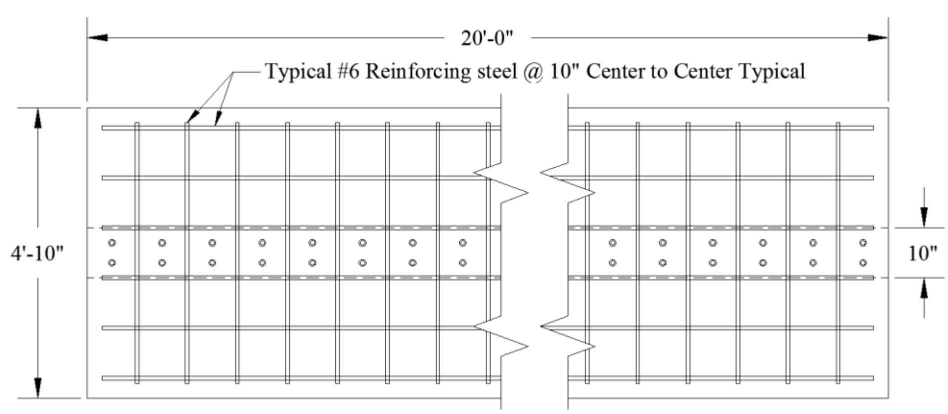

Figure 2. Plan view of the hydrodemolition specimen

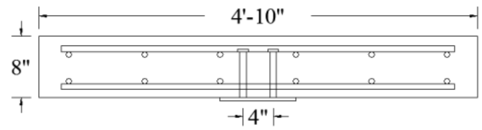

Figure 3. Cross-section view of the hydrodemolition specimen

The hydrodemolition equipment used in this trial has two primary units, a power unit and a demolition unit. The demolition unit, Aqua cutter 710V classic, was used to perform the demolition tasks (see Figure 4).

Figure 4. Demolition unit (Dang 2013)

Technical details for the demolition unit are provided in Table 2. The demolition unit can perform horizontal, vertical, overhead, or circular demolition with a wide range of removal widths.

Table 2. Technical specifications of the demolition unit (Aquajet Systems AB 2013)

Specification	Metric	Imperial
Length minimum	2.65 m	8.69 ft
Length maximum	2.85 m	9.35 ft
Total width	2.00 m	6.56 ft
Minimum width	1.04 m	3.41 ft
Work width range standard	0-2.14 m	0 – 7.02 ft
Working width extended	4.00 m	13.12 ft
Width of track	1.04 – 1.64 m	3.41 – 5.38 ft
Weight	2300 kg	2.54 tons
Height standard	1.6 m (@ 2 m width)	5.25 ft (@ 6.56 ft width)
Height minimum	1.42 m (hood only 1.3 m)	4.66 ft (hood only 4.27)
Max working height standard	7 m	22.97 ft
Drive Source	Diesel engine (Possibility for Hybrid (electric) drive - option)	

The front portion of the demolition unit contains several mechanical systems. The first mechanism is a front roller beam with mechanical stoppers. The demolition attachment moves back and forth transversely along the roller beam within the finite distance between the mechanical stoppers that determine the demolition width. The second mechanism is a roller beam mechanical system that is attached to the nozzle. The nozzle can rotate in both the longitudinal and transverse directions to form multiple angles with the concrete surface. The longitudinal angle is called the oscillating angle and the transverse angle is called the lance attack angle. Both the angle size and operation speed can be manually controlled or preprogrammed. A photograph showing the components of the hydrodemolition mechanism is given in Figure 5.

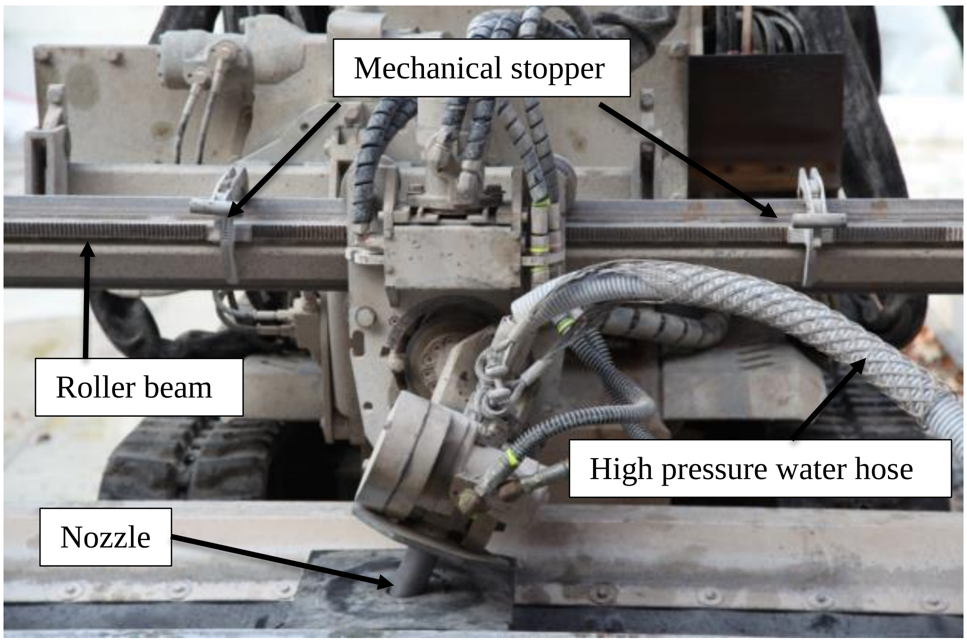

Figure 5. Components of the hydrodemolition mechanism (Dang 2013)

The nozzle is designed to maintain a set distance from the nozzle tip to the concrete surface regardless of the lance attack angle. The effectiveness at breaking concrete is the reciprocal of the lance attack angle; whereas, the effectiveness at removing concrete from the reinforcing steel is proportional to the lance attack angle. For example, a zero lance attack angle is more effective at breaking concrete and a 30° inclination is more effective at cleaning the reinforcing steel. A front close-up view of the hydrodemolition nozzle is shown in Figure 6.

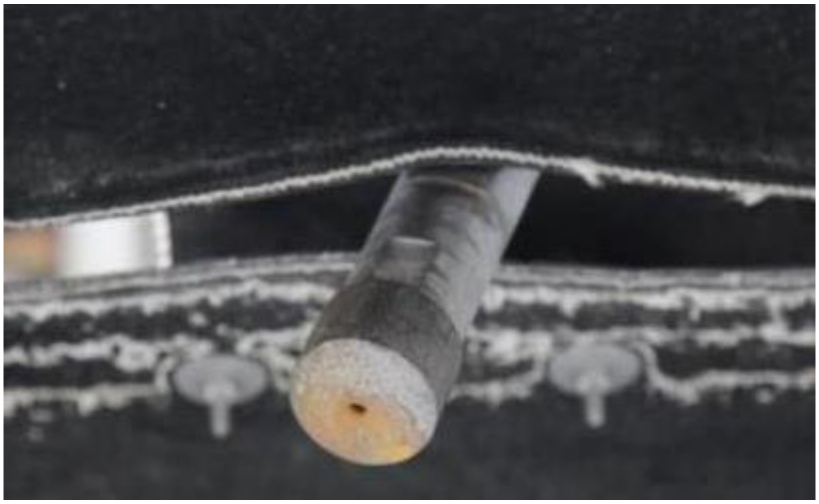

Figure 6. Front close-up view of the nozzle (Dang 2013)

The power unit used in this trial was a diesel-based 600 horsepower engine that could generate 20,000 psi pressure water and pump up to 50 gallons of water per minute. During the hydrodemolition demonstration, the pressure was set to a range of 18,500 to 19,000 psi and consumed 42 gallons of water per minute. A photograph of the power unit is shown in Figure 7.

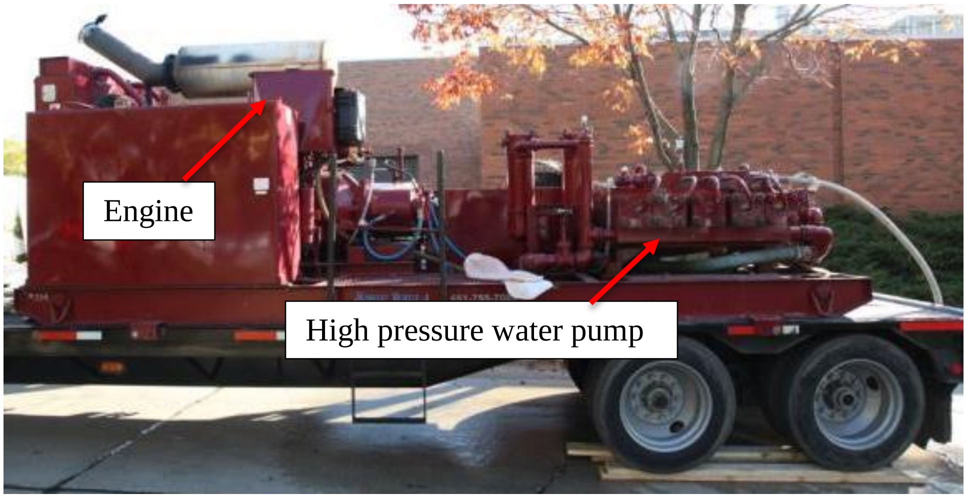

Figure 7. Power unit (Dang 2013)

5.1.1.2 Testing procedures

To conduct the hydrodemolition trial, the operator located the demolition unit on top of the small-scale specimen and then calibrated the demolition unit. A photograph of hydrodemolition site is shown in Figure 8.

Figure 8. Hydrodemolition site (Dang 2013)

The first hydrodemolition test demonstrated the removal of just the top layer concrete. The demolition unit was preprogrammed to perform a 24 in. wide, 4 in. deep, and approximately 18 in. long concrete removal. A photograph taken during the first hydrodemolition test is shown in Figure 9.

Figure 9. Hydrodemolition trial (Dang 2013)

The results of the first hydrodemolition are illustrated in Figure 10.

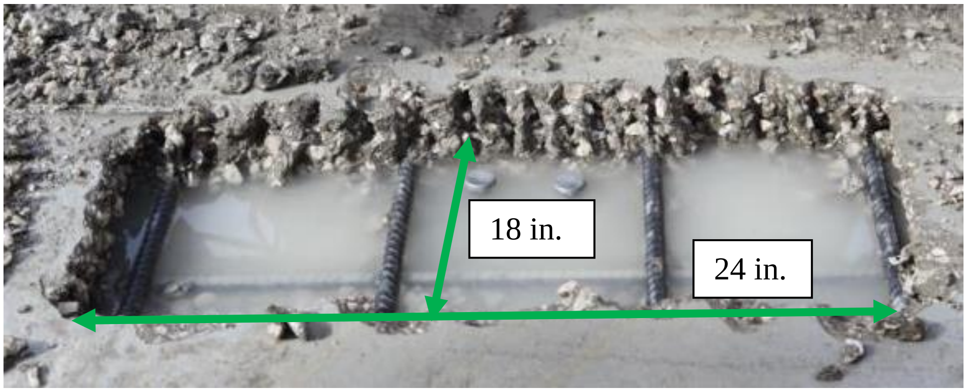

Figure 10. First hydrodemolition test result (Dang 2013)

The second hydrodemolition test demonstrated full-depth concrete removal. The demolition unit performed a 33 in. wide, 8 in. deep (full-depth), and approximately 13 ft long concrete removal. This demolition task took approximately an hour. A photograph of the second hydrodemolition test results are shown in Figure 11. The reinforcing steel, steel plate, and shear studs were left clean and undamaged.

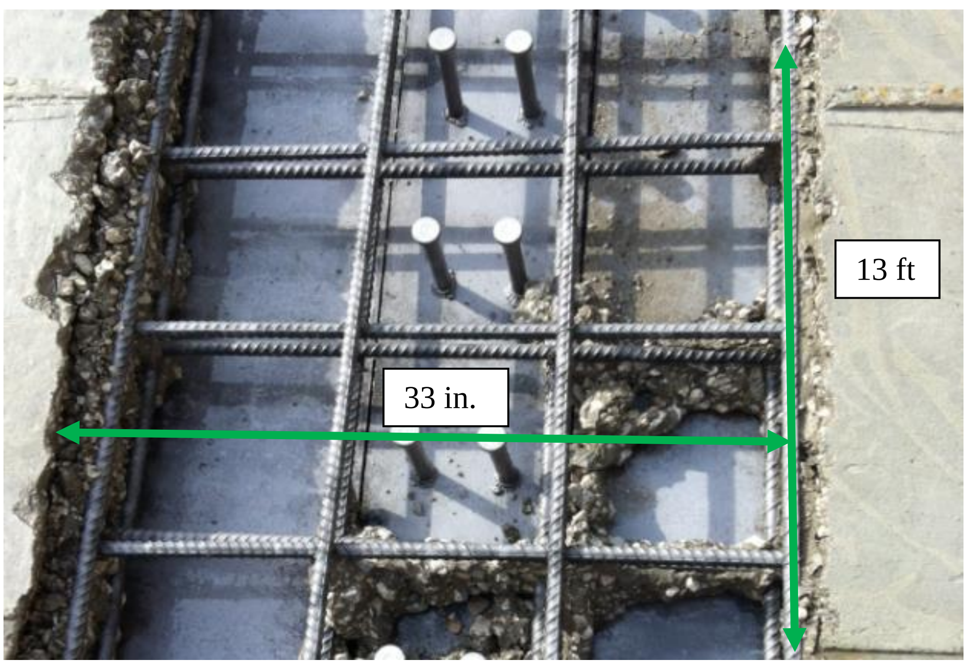

Figure 11. Second hydrodemolition test result (Dang 2013)

5.1.2 Chemical Splitting

The chemical splitting demonstration was performed in October 2013 near the Iowa State University Structural Laboratory. The entire chemical splitting process took approximately one week. Photographs during the splitting process were acquired from a networked camera and were time and date stamped to document the process and effectiveness.

5.1.2.1 Materials and equipment

The chemical splitting specimen was a 20 ft long, 26 in. wide, and 8 in. thick reinforced concrete slab built on a 20 ft long, 10 in. wide, and 0.25 in. thick steel plate. Two shear studs were installed 4 in. apart at a typical 10 in. spacing on the steel plate. A plan view and a cross-section view of the chemical splitting specimen are shown in Figure 12 and Figure 13, respectively.

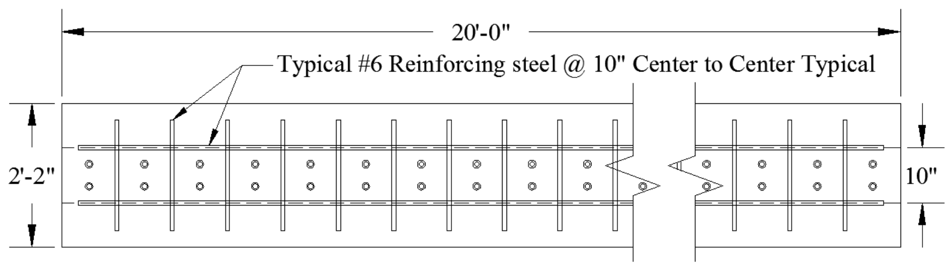

Figure 12. Plan view of the chemical splitting specimen

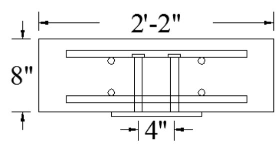

Figure 13. Cross-section view of the chemical splitting specimen

The chemical splitting agent used in this trial is comprised of lime, calcium fluoride, and calcium oxide. This general class of material produces an expansive pressure after hydration. This hydrated mixture is typically placed into predrilled holes arranged in an engineered pattern. For this trial, the chemical splitting specimen was constructed with the hole-pattern shown in Figure 14.

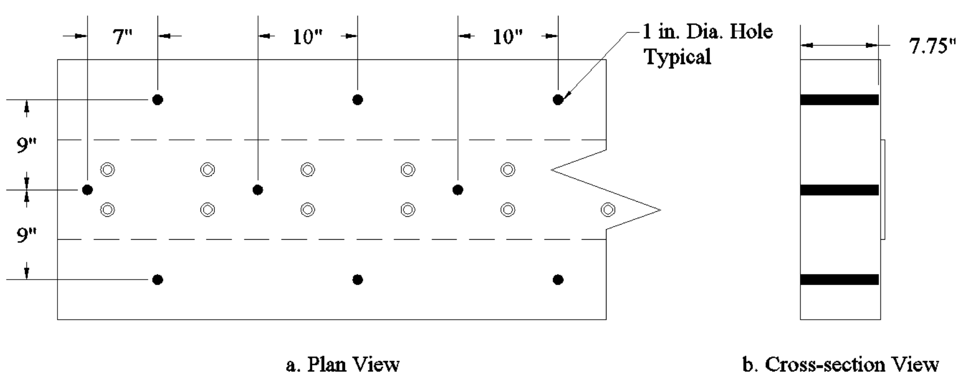

Figure 14. Hole pattern for the chemical splitting specimen

The holes were spaced 10 in. apart longitudinally and 9 in. apart transversely, except near the end of the specimen where these holes were spaced 7 in. from the inner holes and 3 in. from the edge of the specimen. All holes were 7.75 in. deep and 1 in. diameter. In addition to observing the effectiveness of chemical splitting on the simulated bridge deck, a standard concrete cylinder with a predrilled hole in the center was also documented.

5.1.2.2 Testing procedures

To prepare the chemical splitting agent, three liters of cool, clean water were poured into a clean bucket, and 22 lb of chemical splitting agent was mixed with the water for three minutes. Then the holes were filled within five minutes of mixing. All holes filled with the expansive grout were then capped. A photograph during the hole drilling process is shown in Figure 15.

Figure 15. Drilling and cleaning holes taken by the networked camera

The chemical splitting process was monitored via a networked camera for six days following placement of the expansive grout in the preformed holes as shown in Figure 16.

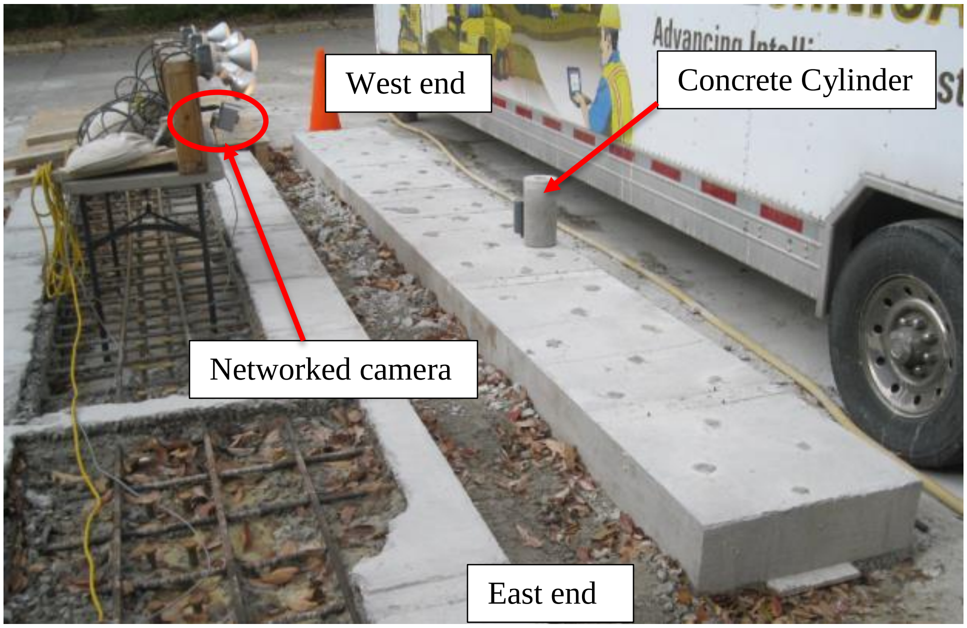

Figure 16. Networked camera and the chemical splitting specimen (Dang 2013)

Photographs were taken every 12 minutes after grout placement. A photograph of the chemical splitting specimen after placement of the expansive grout is shown in Figure 17.

Figure 17. Chemical splitting specimen and the grout

One day after placing the chemical splitting agent, the chemical splitting specimen was observed to be sound (see Figure 18). Although it is possible that micro cracks might have developed, the research team observed no signs of cracks.

Figure 18. Chemical splitting on day one (after 24 hours)

On day two, three major cracks developed on the top of the concrete cylinder (Figure 19). Small cracks initiated on the surface of the concrete slab, and two major cracks formed at the ends of the specimen.

Figure 19. Chemical splitting on day two (after 48 hours)

On days three and four, the cracks initially observed on day two grew and propagated (see Figure 20 and Figure 21). In addition, new cracks developed on the surface of chemical splitting specimen.

Figure 20. Chemical splitting on day three (after 72 hours)

Figure 21. Chemical splitting on day four (after 96 hours)

On day five, a 25-minute rainfall occurred at 1:00 a.m. and another three-hour rainfall started at 9:00 a.m. (see Figure 22). As a result, it is possible that the expansive grout absorbed additional water and may have been rehydrated.

Figure 22. Chemical splitting on day five (after 120 hours)

On day six, the concrete slab remained as one piece (see Figure 23). Large cracks were observed at both ends of the specimen and small cracks were present in the middle of the specimen.

Figure 23. Chemical splitting on day six (after 144 hours)

After day six, there were no further observable changes in any of the previous cracks and no new cracks developed. It was assumed that the expansive capacity of the grout had been reached and the chemical splitting trial was terminated.

5.1.3 Peeling

The peeling deck removal method was simulated by restraining the peeling specimen and applying uplift forces using two hydraulic jacks on each side of the steel girder under the concrete deck. The peeling trial was performed for two types of shear connectors at different times. The test was performed on the three shear stud connector section on December 11, 2013 and on the two shear stud section on January 8, 2014.

5.1.3.1 Materials and Equipment

The peeling specimen was a 20 ft long, 26in. wide, and 8 in. thick reinforced concrete slab built on a 23 ft long steel H-pile (HP 10 x 57). A plan view and a cross-section view of the peeling specimen are shown in Figure 24 and Figure 25.

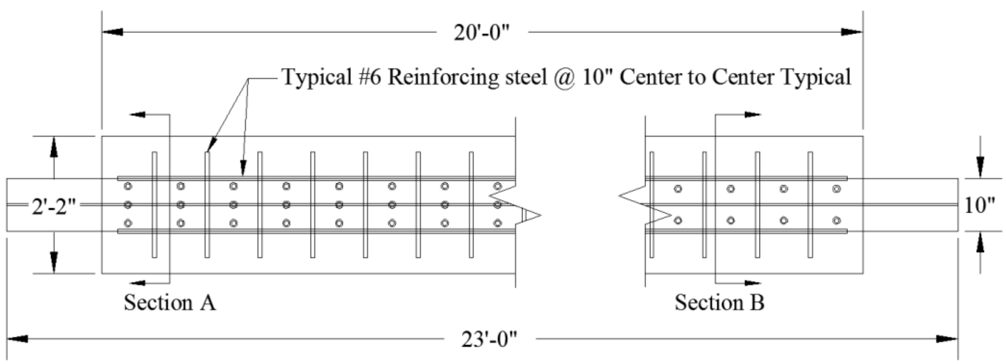

Figure 24. Plan view of the peeling specimen

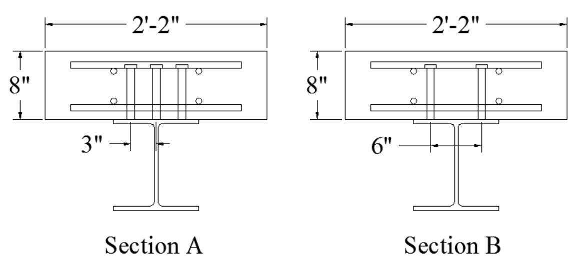

Figure 25. Two cross-section views of the peeling specimen

The peeling specimen included two equal sections (sections A and B in Figure 24). Section A was fabricated with three shear studs at 3 in. spacing transversely. Section B was constructed with two shear studs at 6 in. spacing transversely. All of the shear studs were welded at a typical 10 in. spacing longitudinally on the steel HP-section.

5.1.3.2 Testing Procedures

During each trial, the concrete deck was removed from one “free” end and progressed towards the middle of the specimen. The peeling simulation consisted of a series of repeated loading steps, which would represent repeated placement of the peeling equipment. During each loading step the same series of basic steps were followed. First, the specimen was securely tied to the ground. Second, two hydraulic jacks were placed under the concrete slab on each side of the steel girder (Figure 26). Third, vertical loads were slowly applied until failure occurred. Fourth, the failure mode and peak load were documented and the loading apparatus moved to the next location.

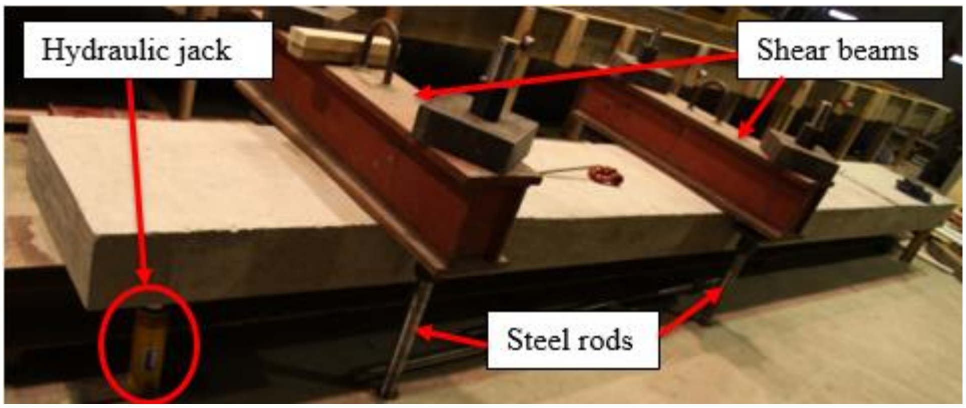

Figure 26. Peeling trial setup

Peeling of Section A (3 Shear Studs)

The first peeling test result is illustrated in Figure 27 and Figure 28. The failure appeared to be relatively symmetric about the longitudinal centerline of the steel girder. The peak load for this test was 21.1 kips.

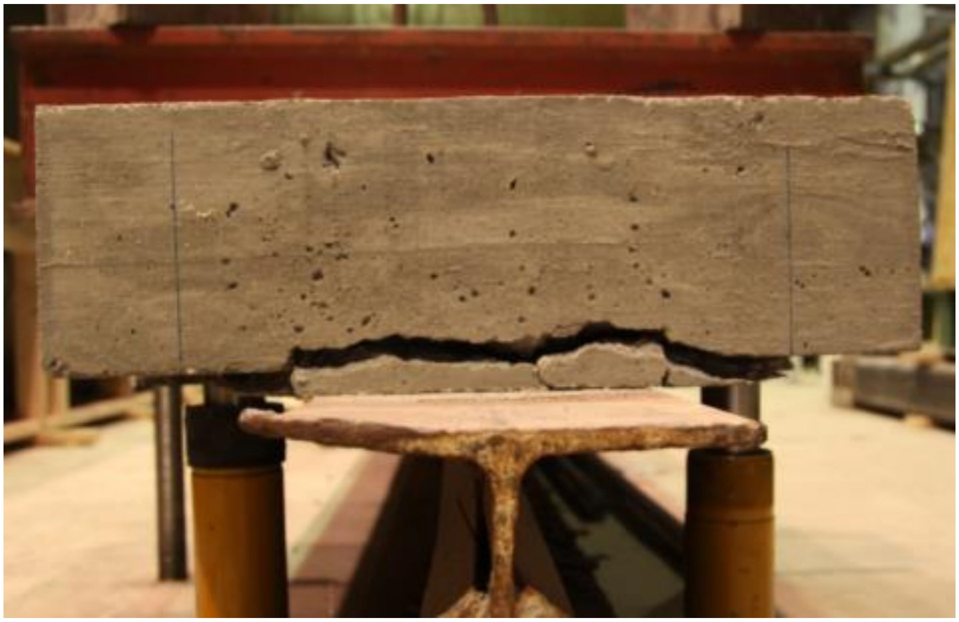

Figure 27. Front view of the first peeling test (3 shear studs) (Dang 2013)

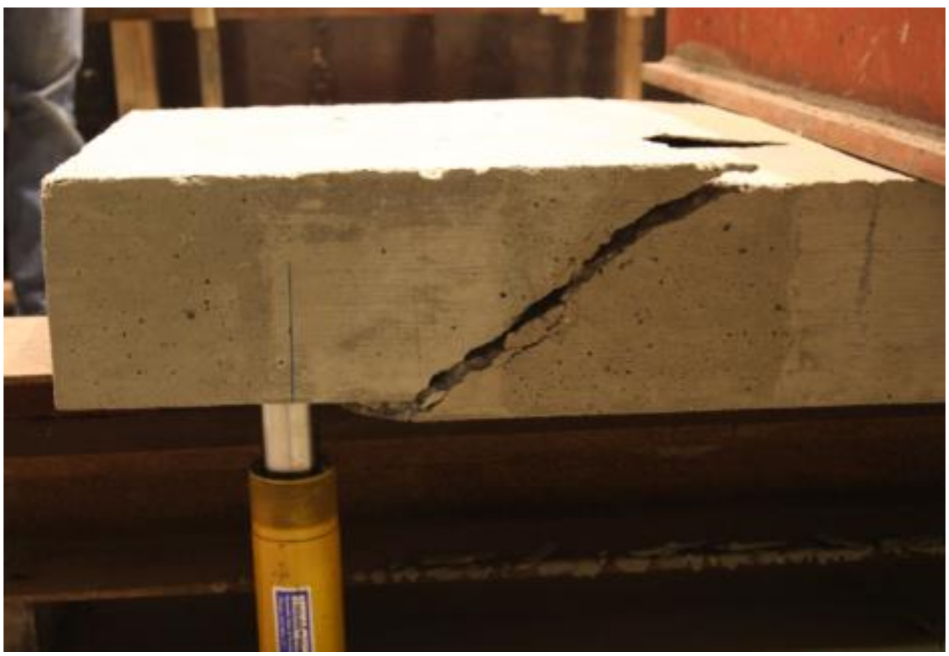

Figure 28. Side view of the first peeling test (3 shear studs) (Dang 2013)

The second test apparatus was modified by adding a steel plate to distribute the hydraulic jack load over a larger area. An image of the second peeling test is shown in Figure 29. Only one side of the concrete slab failed and broke into two large pieces. The peak load for this test was 41.8 kips.

Figure 29. Second peeling test (3 shear studs) (Dang 2013)

The third peeling test resulted in only one side failing since the concrete on the opposite side had been damaged during the second test. The peak load for this test was 36.1 kips. A photograph of the third peeling test result is shown in Figure 30.

Figure 30. Third peeling test (3 shear studs) (Dang 2013)

The fourth peeling test was a punching shear failure on one side of the specimen. The peak load for this test was 30.0 kips. A photograph of the fourth peeling test result is shown in Figure 31.

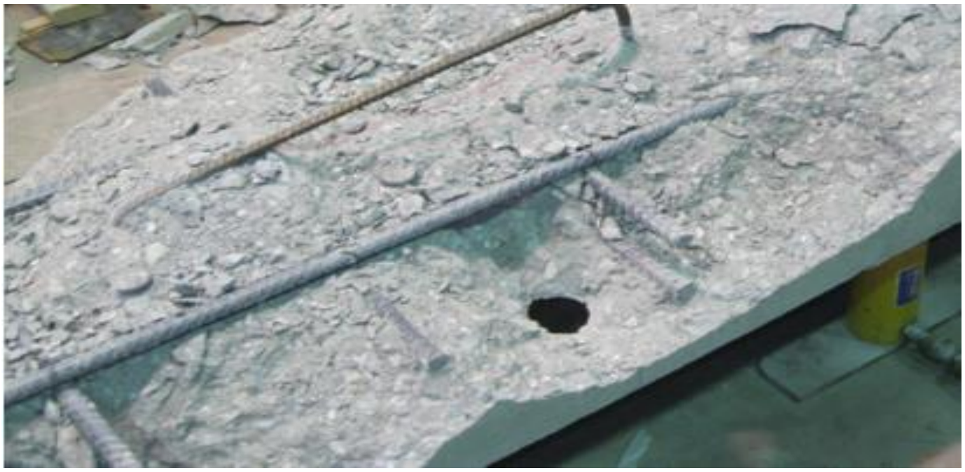

Figure 31. Fourth peeling test (3 shear studs) (Dang 2013)

The fifth peeling test resulted in two pieces of concrete being broken off the concrete slab with the failure pattern similar to previous failures. The peak load for this test was 26.7 kips. A photograph of the fifth peeling test is shown in Figure 32.

Figure 32. Fifth peeling test (3 shear studs) (Dang 2013)

Peeling of Section B (2 Shear Studs)

The peeling trial for section B (2 shear studs) had similar failures. Compared to the loads applied to section A, the loads were applied more consistently from the end of the specimen to the middle of the specimen. The testing ensured every peeling test was loaded from a free end. The first test failed in shear as shown in Figure 33 and Figure 34. The peak load for this test was 15.8 kips.

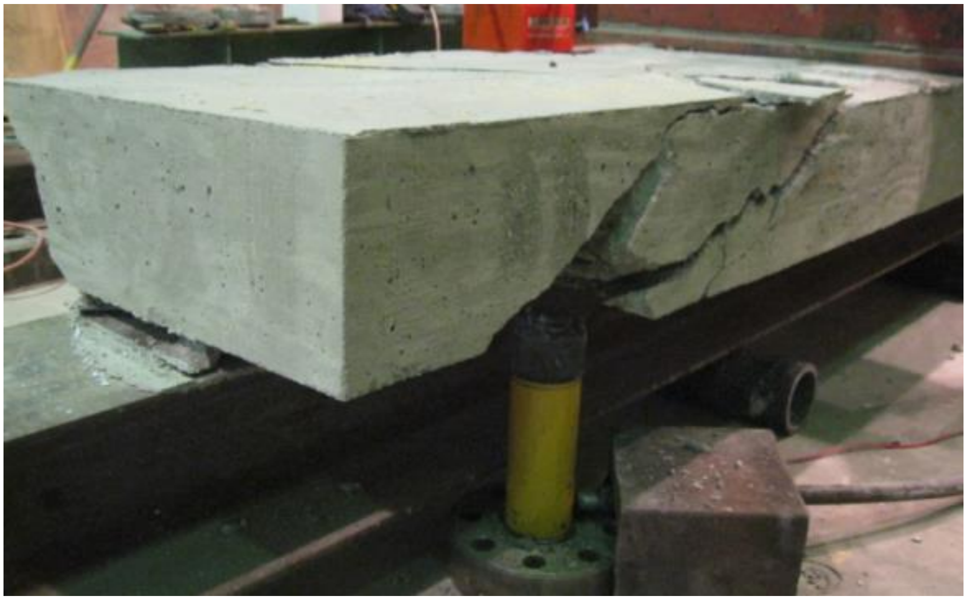

Figure 33. Side view of the first peeling test (2 shear studs) (Dahlberg 2014)

Figure 34. Top view of the first peeling test (2 shear studs) (Dahlberg 2014)

The section B peeling trial removed most of the concrete by multiple peeling tests conducted one after the other. A photograph of the section B peeling trial is shown in Figure 35. The peak loads were summarized in following result section.

Figure 35. Second peeling test (2 shear studs) (Dahlberg 2014)

5.2 Results and Discussion

This section discusses the results of the small-scale trials of bridge deck removal by hydrodemolition, chemical splitting, and peeling methods.

5.2.1 Hydrodemolition

Hydrodemolition is well suited to both partial and full-depth removals. The pressure controlled demolition protects the steel girders, shear connectors, and reinforcing steel from unintended damage. This method produces no dust and induces no vibration.

Though hydrodemolition yields a high quality deck removal, this method has several drawbacks. Hydrodemolition produces at least an equal amount of wastewater, which needs to be contained and treated. The power unit is noisy (range of 90 to 100 dB). Shadowing might occur when steel elements shield the concrete beneath them.

5.2.2 Chemical Splitting

Chemical splitting produces no noise, dust, or vibration, but even in the best cases requires a long time to break the concrete deck and needs a method to catch falling materials. In this study, this method was not an effective deck removal method. The result of chemical splitting after six days (144 hours) is illustrated in Figure 36. The cracks caused by chemical splitting were not sufficient to remove the concrete deck from the steel girders.

Figure 36. Chemical splitting on day six (Dang 2013)

5.2.3 Peeling

The peak loads measured during the peeling trials for Section A (three shear studs) range from 11.8 kips to 41.8 kips as shown in Table 3.

Table 3 Peeling loads for Section A

Load Number	1	2	3	4	5	6	7	8	9
Peak Load (kips)	21.1	41.8	36.1	30.0	26.7	31.2	13.6	12.2	11.8

The peak loads recorded during the peeling trial for Section B (two shear studs) are between 9.2 kips and 38.3 kips as shown in Table 4.

Table 4 Peeling loads for Section B

Load Number	1	2	3	4	5	6	7	8	9	10	11
Peak Load (kips)	15.8	9.3	22.0	21.4	9.9	19.4	25.4	31.0	9.4	38.3	9.2

The peeling method may offer contractors some advantages such as high production rate, low cost, and simplified operation. Peeling did not damage steel elements in this trial. However, concrete on top of steel girders and around shear connectors may need additional removals by using other methods such as jackhammering. This method yields dust, noise, and falling materials. Large loads generated during the peeling process might cause undesirable vibrations or deformations. Safety, structural adequacy, and stability are other concerns when equipment is working on bridges.

6. SHEAR STRENGTH EVALUATION FOR PARTIAL CONCRETE REMOVAL AROUND SHEAR CONNECTORS

Chapter 6 describes laboratory testing completed to understand how shear connector, static shear strength is impacted when variable amounts of concrete are removed from around the shear connector. This evaluation focuses solely on the shear connector strength with respect to the extent and quantity of concrete removal; no consideration was given to the quality of the concrete left in place. In short, this study sought to answer the question as to whether it is necessary to remove 100% of the concrete during a deck replacement.

6.1 Methods

Three different concrete removal levels were evaluated as shown in Table 5.

Table 5. Concrete removal group for shear strength evaluation

Group	Specimen Description
Control	100% concrete removal (100% new concrete)
Experiment A	75% concrete removal (25% old concrete and 75% new concrete)
Experiment B	50% concrete removal (50% old concrete and 50% new concrete)

Specimens were prepared in three steps. First, concrete was placed around the shear connectors. Second, the concrete was removed to the desired levels (i.e., 100%, 75%, and 50% concrete removed). Third, the complete specimens were fabricated by placing new concrete around the entire assembly. Note, however that the control group specimens skipped the first and second steps to simplify the fabrication process.

A total of 27 specimens were fabricated. These specimens had three types of shear connector: stud (7/8 in. diameter), channel (C5×6.7), and angle-plus-bar (6×6×3/8 angle and 1 1/4×3/4 bar). Each type of shear connector was further subdivided into three groups based upon the amount of concrete removed, including three specimens in the control group (100% removal), three specimens in the experiment A group (75% removal), and three specimens in the experiment B group (50% removal).

6.1.1 Specimen Preparation

Specimen preparation consisted of steel fabrication, initial concrete placement, concrete removal, and final specimen fabrication. The steel specimen fabrication consisted of welding shear connectors on both flanges of 1.5 ft long steel girder (W10×60) section. Each shear connector was welded 6 in. from one end of the steel girder to the geometric center of the shear connector. Three-dimensional renderings of the steel specimens are shown in Figure 37.

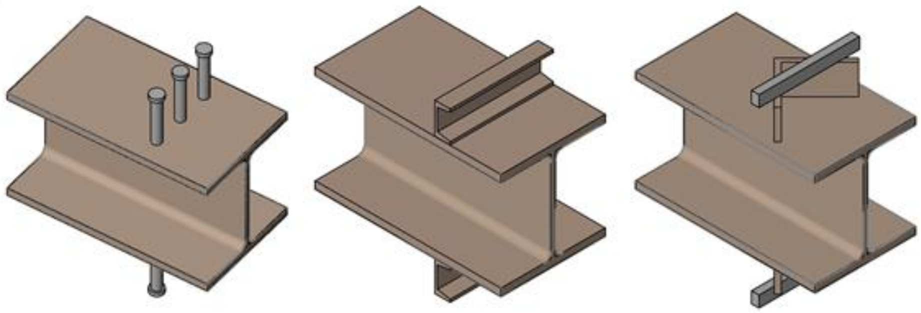

Figure 37. Shear connectors (from left to right: shear studs, channel, and angle-plus-bar)

After all shear connectors were welded to the steel girders, concrete formwork was constructed for the initial concrete placement (Figure 38). The formwork was designed to allow for a concrete cover of 6 in. on both sides of the shear connector, simulating a concrete deck with a thickness of 8.75 in.

Figure 38. Constructed steel specimens and concrete formwork (Dang 2013)

Initially, 18 specimens were fabricated using Iowa DOT standard C-4WR concrete mix and then cured for 28 days (Figure 39).

Figure 39. Eighteen specimens after initial concrete placement (Dang 2013)

The eighteen specimens consisted of six specimens with each type of shear connector. The concrete around these specimens was then removed to the 50% and 75% levels. The control group (100% removal) was constructed by casting concrete on new steel specimens and thus simulating the case where 100% of the concrete was removed and then completely replaced.

After curing the concrete for 28 days, a rotary hammer was used to remove the concrete to the desired level. The level of concrete removal was controlled by weighing the removed concrete. Figure 40 shows a photograph when the left side has reached 75% removal and the right side has reached 50% removal. Note that the right side will have additional material removed until it closely matches the 75% removal shown on the left side.

Figure 40. Partially removed concrete specimen (Dang 2013)

The 27 specimens (9 with 50% removal, 9 with 75% removal, and 9 bare steel specimens) were then placed in new concrete formwork. The new concrete placement encapsulated the old concrete to represent a replaced deck. The final specimen configuration is schematically illustrated in

Figure 41, Figure 42, and Figure 43 show the specimens in the formwork. All specimens were then cured for 28 days before testing.

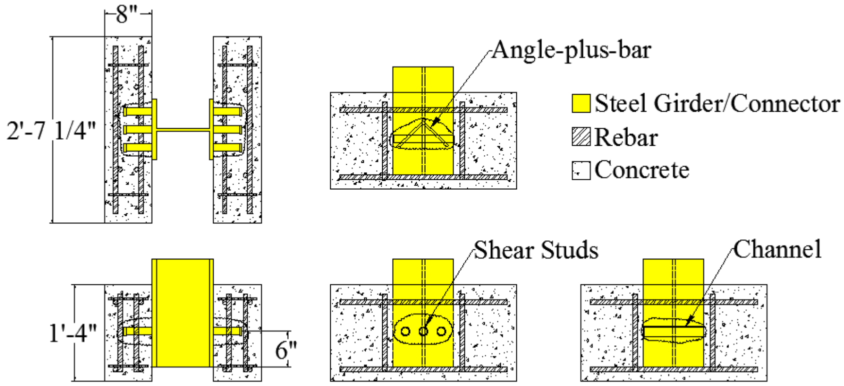

Figure 41. Schematic dimensions of specimens

Figure 42. Partially removed concrete specimens and formwork (Dang 2013)

Figure 43. Specimens, reinforcing steel, and formwork (Dang 2013)

6.1.2 Testing Procedures

The steel frame used to load the specimens consisted of four hollow steel columns, four rectangular tubes, and a wide flange steel girder as shown in Figure 44.

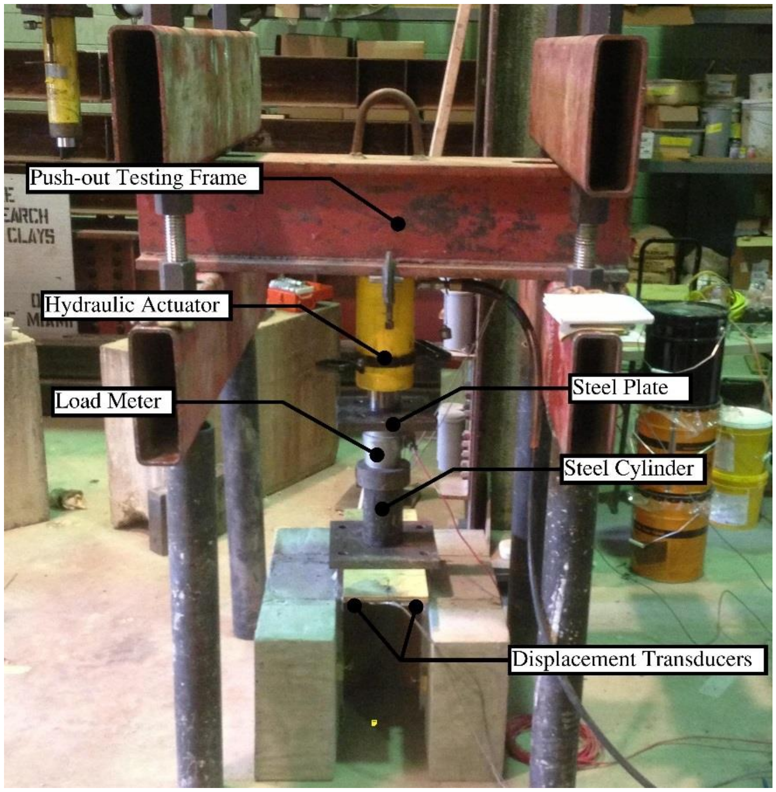

Figure 44. Shear capacity testing setup (Dang 2013)

Displacement transducers were used to measure the relative displacement between the concrete deck and the steel girder at the four corners of the specimen. Next, loads were gradually applied to each specimen with a hydraulic load actuator. Testing was conducted until each specimen failed. The load and displacement were monitored with a computerized data acquisition system.

Two types of failures, including shear connector failure and concrete failure, were observed during testing. An example of a specimen with a shear connector failure is shown in Figure 45.

Figure 45. Typical shear connector failure (Dang 2013)

The shear connector failure results either one or both sides of the specimen breaking apart. An example of a specimen with a concrete failure is shown in Figure 46. This type of failure is exemplified by concrete cracks that initiate on the bottom of the specimen and then propagate quickly as loads are gradually applied.

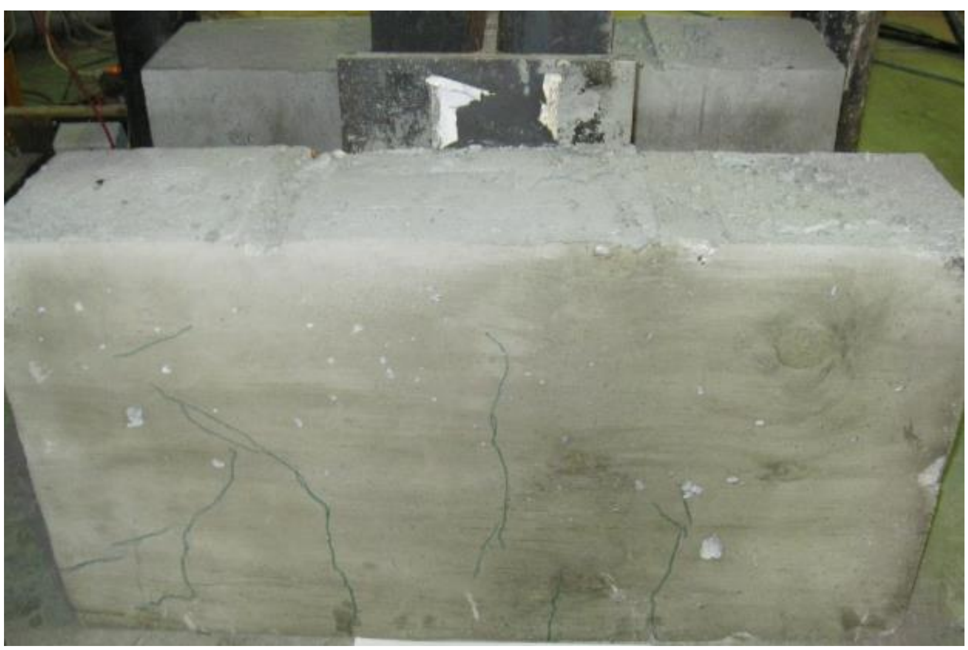

Figure 46. Typical concrete failure (Dang 2013)

6.2 Results and Discussion

The two principal metrics for evaluating the impact of concrete removal on shear strength included the applied loads and the relative displacement between the concrete and steel. The load per connector was calculated as one-half of the total applied load. The relative displacements at the four corners of the specimen were averaged to produce a single load displacement relationship.

6.2.1 Stud Shear Connectors

The load versus the average displacement for stud shear connectors is illustrated in Figure 47.

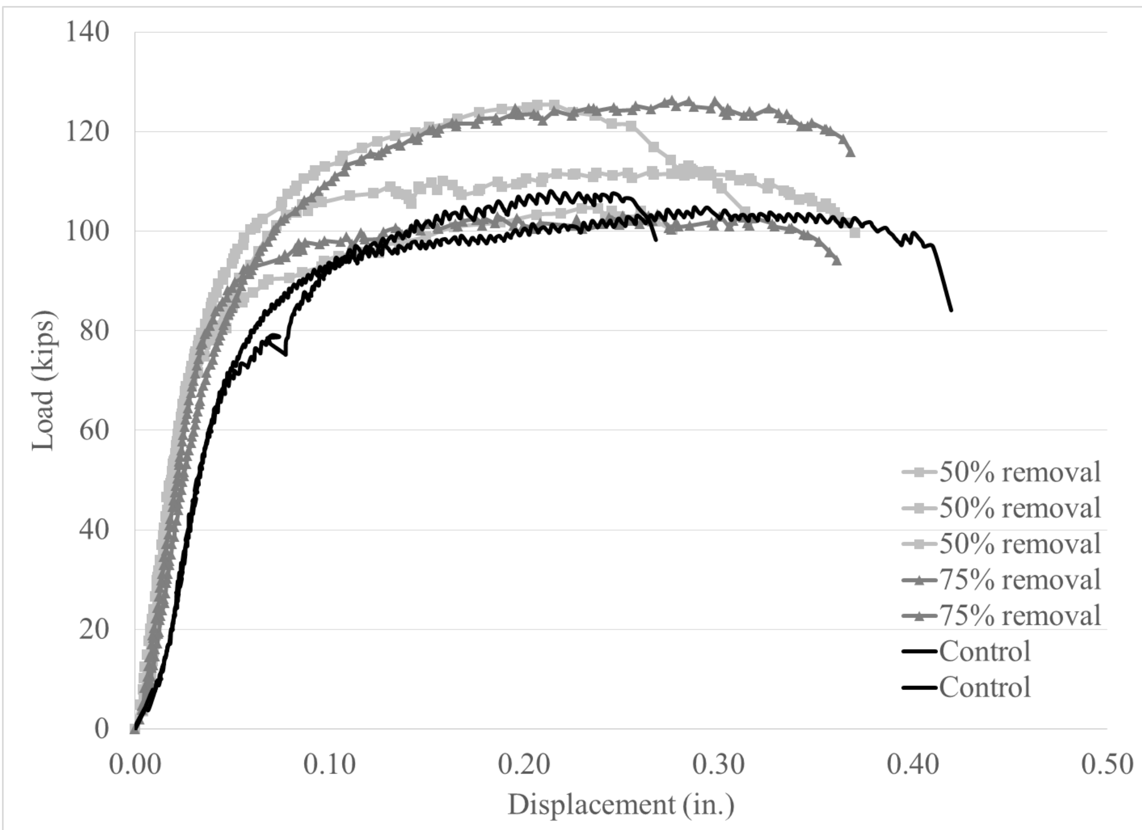

Figure 47. Load verses the average displacement for stud shear connectors

The shear strength is slightly higher in the 50% removal and the 75% removal when compared with the control group. Also, the stiffness appears to be slightly increased when less concrete is removed.

The experimental loads for the stud shear connectors are shown in Table 6.

Table 6. Predicted and experimental loads for the stud shear connectors

Specimen	Experimental load (kips)
50% removal	105
50% removal	126
50% removal	112
75% removal	126
75% removal	104
75% removal	108
Control	108
Control	105

The measured peak load for the stud shear connectors ranged from 104 to 126 kips. The average control peak load was 106.5 kips. The ratio load for the partial removal to the control stud shear connectors ranged from 0.98 to 1.18.

Overall, Table 6 shows insignificant differences between partial and complete concrete removals for the ultimate shear strength. The testing results indicate the ultimate shear strength of stud shear connectors is basically insensitive to the quantity of concrete removed.

6.2.2 Channel Shear Connectors

The load versus the average displacement for the channel shear connectors show similar behaviors between the 50% removals and the control group, as shown in Figure 48.

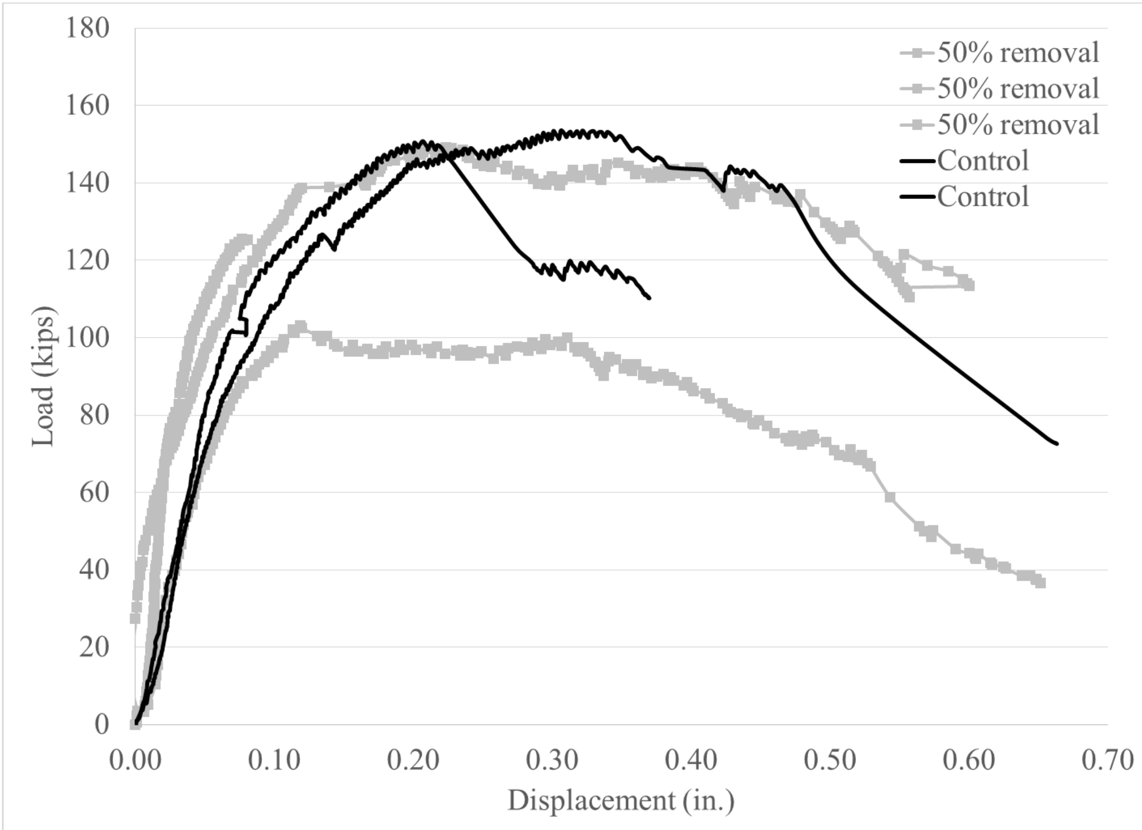

Figure 48. Load versus the average displacement for channel shear connectors

Full data for the 75% removal specimens were not retrieved because of technical issues (e.g., only peak load was obtained). One of the 50% removals had lower shear strength than the other two and was attributed to poor specimen construction.

The experimental loads for the channel shear connectors are shown in Table 7.

Table 7. Predicted and experimental loads for channel shear connectors

Specimen	Experimental load (kips)
50% removal	149
50% removal	126
50% removal	103
75% removal	150
75% removal	125
75% removal	130
Control	154
Control	151

The experimental loads vary from 103 to 154 kips. Seven of the channel connector specimens had concrete crushing-splitting failure modes. One had a channel fracture on one side of the specimen. The ratios of load for the partial removal to full removal vary between 0.68 and 0.98. These results indicated that the channel shear connector is sensitive to the amount of concrete removal.

6.2.3 Angle-Plus-Bar

The load versus the average displacement for the angle-plus-bar shear connectors is shown in Figure 49. The slopes are approximately the same in the elastic region. Variations within one particular concrete removal level are similar to the variations within the control group.

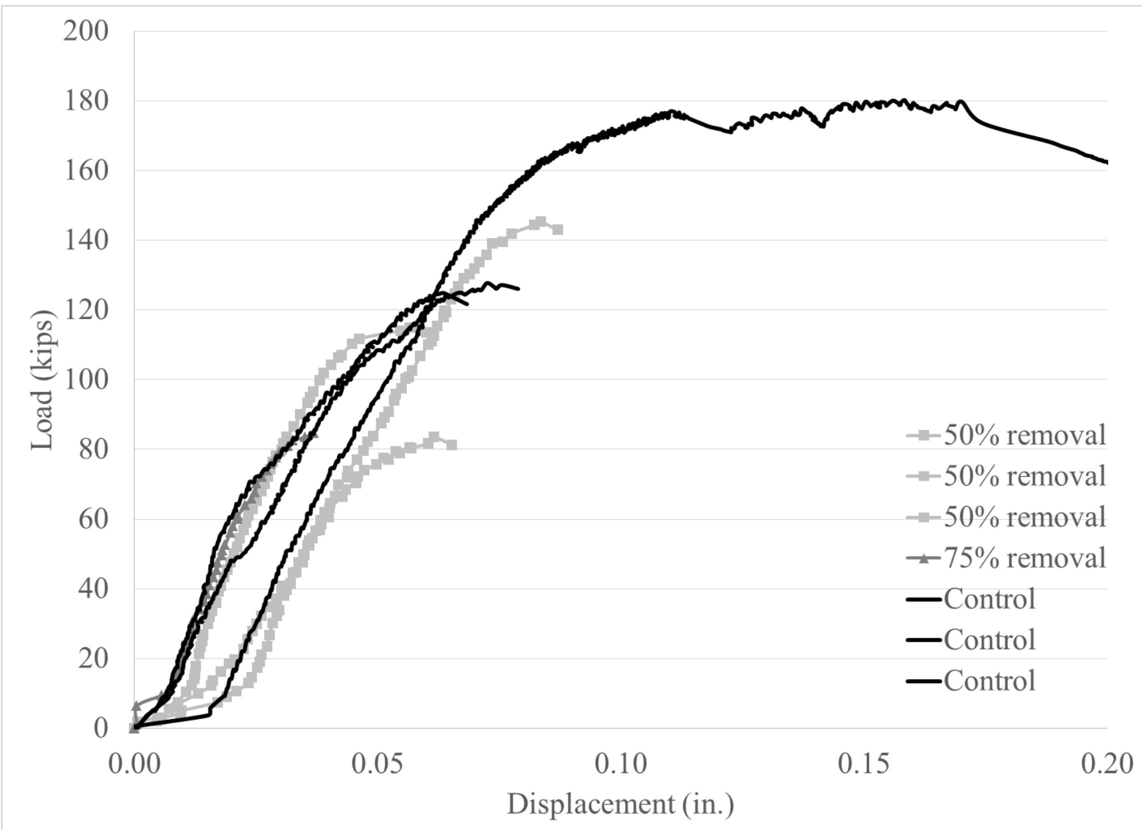

Figure 49. Load versus average displacement of the angle-plus-bar shear connectors

The experimental peak loads for the angle-plus-bar shear connector specimens are shown in Table 8.

Table 8. Predicted and experimental loads for angle-plus-bar shear connectors

Specimen	Experimental load (kips)
50% Removal	115
50% Removal	84
50% Removal	146
75% Removal	85
75% Removal	143
Control	125
Control	180
Control	128

The experimental loads are scattered between 84 and 180 kips with the control having an average peak load of 144 kips. Four specimens had angle fractures on one side; three specimens had angle fractures on both sides; and one specimen had a concrete crushing-splitting failure. As with the angle-plus-bar shear connector, some difference in peak load was observed with a lower percentage of concrete removed.

7. CONCLUSIONS AND RECOMMENDATIONS

This chapter summarizes the conclusions developed based on interviews, surveys, and workshops; and provides conclusions based on the results of the small-scale trials and shear strength evaluations.

7.1 Conclusions

This research explored methods for removing concrete decks from steel girder bridges. Interviews with bridge owners and contractors indicated that concrete deck replacement was more economical than replacing the entire superstructure under the assumption that salvaged superstructures have adequate remaining service life and capacity. Surveys and workshops discussed the advantages and disadvantages of various deck removal methods. Small-scale trials explored three promising deck removal methods: hydrodemolition, chemical splitting, and peeling. Push-out tests validated that removing all concrete around shear connectors may not, in some cases, be necessary from a shear strength perspective.

7.1.1 Interview, Survey, and Workshop Key Findings

- Sawing, use of percussive tools (e.g., jackhammers and rig-mounted breakers), and hydrodemolition are three commonly used deck removal methods identified through interviews, surveys, and workshops.
- Damage caused by deck removal methods and equipment is not considered in cost estimates or other decisions because the damage is typically minimal.
- Hydrodemolition has the unique advantage that it does not damage steel girders.
- Contractors usually have equipment that can be used for peeling.
- Grinding, welding, heat-straightening, flange build-up or replacement are currently used to repair damaged superstructures.
- Ten of the 28 state DOTs responding to the project survey reported that they specify deck removal methods and equipment in special provisions.
- Removing bridge decks takes approximately the same amount of time as removing entire superstructures when bridges are over waterways.
- Bridge deck removal takes longer and is more delicate work than removing the entire superstructure or bridge.
- Concrete deck replacement is more economical than replacing the entire superstructure under the assumption that salvaged superstructures have adequate remaining service life and capacity.

7.1.2 Small-Scale Trial Key Findings

- Hydrodemolition is well suited for both partial and full-depth concrete removals.
- Hydrodemolition did not damage the steel elements in the trial, which validated the survey results.
- Hydrodemolition consumes a large quantity of water and produces wastewater, slurries, and debris.
- Hydrodemolition might be cost prohibitive, depending upon the cost of water sources, wastewater treatment, and disposal.
- Chemical splitting was found to not be an effective deck removal method.
- Peeling is a simple, economical deck removal method.

7.1.3 Shear Strength Evaluation Key Findings

- The shear strength of the stud shear connector is insensitive to the quantity of concrete removed.
- The shear strength of the channel connector is sensitive to the amount of concrete removed.
- Some difference in the shear strength of the angle-plus-bar connector was observed in a lower percentage of concrete removed.

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APPENDIX A. SURVEY OF DOTS ON CURRENT PRACTICE

- Please indicate which state you completing this survey?

Alabama	Alaska	Arizona	Arkansas	California
Colorado	Connecticut	Delaware	Florida	Georgia
Hawaii	Idaho	Illinois	Indiana	Iowa
Kansas	Kentucky	Louisiana	Maine	Maryland
Massachusetts	Michigan	Minnesota	Mississippi	Missouri
Montana	Nebraska	Nevada	New Hampshire	New Jersey
New Mexico	New York	North Carolina	North Dakota	Ohio
Oklahoma	Oregon	Pennsylvania	Rhode Island	South Carolina
South Dakota	Tennessee	Texas	Utah	Vermont
Virginia	Washington	West Virginia	Wisconsin	Wyoming

Other Agency (please specify) _____________

- For the steel and precast concrete girder type bridges indicated below, does your state have provisions and/or guidelines for full-depth concrete deck removal (re-decking)?
- Which removal methods have previously been used and are currently allowed within your state for decks placed on steel and precast concrete girders?
- Using the drop down menus, please describe the typical cost, duration, safety, and noise of each method you previously indicated.
- Please describe how likely the methods you have indicated will cause damage to the girder flange?
- In your experience, have you witnessed the methods indicated cause damage to the shear connectors? If so, please describe.
- If a steel I-girder's top flange is damaged during deck removal, what actions are taken for varying degrees of damage?
- If a Standard AASHTO girder's top flange is damaged during deck removal, what action are taken for varying degrees of damage?
- If a Bulb-T girder's top flange is damaged during deck removal, what actions are taken for varying degrees of damage?
- In the event where stay-in-place forms were used for deck construction, how is the deck removed?
- What new deck removal approaches or innovative ideas would you recommend if the project was not restricted by time and cost?
- May we at the Bridge Engineering Center contact you directly with any further questions we may have? If so, please provide your direct contact information.

Name:	Agency:
Address:	City/Town:
State:	ZIP:
Email Address:	Phone Number:

APPENDIX B. INTERVIEW QUESTIONNAIRE ON DECK REMOVAL

States are looking for cost-effective methods of removing bridge deck from steel girders to extend the service life of bridge. The cost analysis is comparing the bridge deck removal with promising methods versus complete removal of bridge deck and steel girder. Actual cost data analysis will provide foundation for making future cost-based replacement decisions.

Purpose of Interview:

- Understand estimate of bridge deck removal from contractor's perspective.
- Discuss cost associate factors in concrete deck removal (Evaluate factor's sensitivity)
- Identify cost-factor related relationship.

General Questions

- Name:
- Current Title and position description:
- Duration with Estimating and experience at different titles:
- Past bridge deck replacement projects:

Specific Questions:

Methods

- What are the conventional methods of removing concrete deck from steel girders?
    - Saw Cutting, Percussive tools (Jackhammer, Whip-hammer, and Breaker), Drilling, Splitting, Blasting, Ball and Crane.
    - New methods (Hydrodemolition, Chemical Splitting, Peeling Off, Milling, Crusher, Thermal Cut)
- When selecting methods, what factors do you consider?
    - Project type, size, location, traffic, environment impact and sustainability.
    - Cost, Damage, Safety,
    - Vibration, Dust, Noise, Falling Material,
    - Time/Duration (Efficiency), Length of Concrete Deck (Quantity), Equipment,
- Do you consider damage when selecting different deck removing methods?

Damages

- What are the typical damages to steel girder?
    - Shear connector damages, Saw cut top flange, indentation, local damages (distortion, deformation), Fatigue, Crack,
    - Other damage?

- How do you assess the damages?
  - Level of damage? Damage rating?
- What are the repairing means and methods?
  - Heat-straightening
- Based on what criteria the damages would be more restricted in a project? How does it affect method selections and cost?
  - DOT provision
  - Project details
  - Contractor's means and methods
  - Repairing cost

Cost and Estimate

- How do you estimate the cost of a bridge deck removal project?
  - Unit price, unit labor, crew and equipment
- What would be the typical duration range of a bridge deck removal project?
  - Duration of removing concrete deck
  - Duration of new concrete deck
  - Formwork and placement of concrete
  - Installation of precast concrete
- What are the cost for repairing damages? How does damage level play into estimate?
  - How to estimate?
  - What are historical values?
- Which would be more cost-effective when comparing extra days of removing concrete deck carefully and extra cost of repairing damages to steel girders versus the cost of new steel girders?
  - Is the comparison sensitive to any other factor?
  - Bridge Length? Damages (amount and level)? Steel price?
- As you know, cost is very dependent on the removing methods and methods. How would you determine the most cost-effective means and methods to removing concrete decks from steel girder?
  - Start from preliminary consideration to the end of construction.
  - Does it ever change? Lessons learn?
- Is the current practice still very cost-effective or the new methods are taking over?
  - Why it would be that way?
- How would you provide water source for hydrodemolition and manage the wastewater?
  - What are those additional items' costs? Still cost-effective than conventional methods?
- Did you remove concrete deck by peeling off or chemical splitting methods before?
  - If so, how well does it work? Is it cost-effective? What are costs?
- How to get the unit price data on bridge deck removal project from state DOT websites?
  - Can you provide a guidance?
- Can you provide itemized cost data for past projects on three methods?
  - Conventional methods (i.e., saw cutting + jack hammering)
  - New methods (i.e., hydrodemolition)

- Replacement of both concrete deck and steel girder
- Cost of removing
- Cost of new girder

- Within the projects experience, do you see any relationship between the length of the bridge and the unit cost?
  - Concrete Deck Quantity (Length, Width, Thickness)