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Concrete Cutting Refinement for Crater Repair

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Abstract

Research was conducted at the U.S. Army Engineer Research and Development Center in Vicksburg, MS, to evaluate saw-cutting equipment for use by crater repair teams in airfield damage repair (ADR) scenarios. The evaluation included measuring the saw-cutting rates and cutting-bit wear of commercial saw-cutting equipment in both soft and hard aggregate-mixed concrete. The investigated equipment included the Vermeer RW1236W and CC1531, Caterpillar SW45 and SW60, and Ditch Witch H1140 wheel saws outfitted with various cutting bits. This report presents the technical evaluation of the various saw technologies and tools for improving the efficiency of sawing around damaged pavement associated with crater repair. Results indicate that the Vermeer saws with the Kennametal SM04 cutting bits provide the most efficient saw-cutting rates with the least wear, followed by the Caterpillar wheel saws with the Kennametal RP15 cutting bits. These two saw technologies are recommended to be considered for use by ADR crater repair teams.

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Preface

This study was conducted for the U.S. Air Force's Civil Engineer Modernization Program sponsored by Headquarters, Air Combat Command in Langley Air Force Base, VA. Headquarters, U.S. Air Force Civil Engineer Center (AFCEC) located at Tyndall Air Force Base, FL, provided funding for the research project described in this report, and Dr. Craig Rutland, AFCEC, provided guidance during the project.

The work was performed by the Airfields and Pavements Branch (APB) of the Engineering Systems and Materials Division (ESMD) with quality control testing provided by the U.S. Army Engineer Research and Development Center's (ERDC) Materials Testing Center within the Geotechnical and Structures Laboratory (GSL). Jeb S. Tingle, Acting Technical Director for Force Projection and Maneuver Support, was the ERDC Airfield Damage Repair program manager. At the time of publication, Dr. John F. Rushing was Acting Chief, APB; Dr. Larry N. Lynch was Chief ESMD; Dr. Will McMahon was Acting Deputy Director of ERDC-GSL, and Dr. William P. Grogan was the Acting Director.

LTC John T. Tucker III was the Acting Commander of ERDC, and Dr. Jeffery P. Holland was the Director.

Unit Conversion Factors

Multiply	By	To Obtain
cubic feet	0.02831685	cubic meters
cubic inches	1.6387064 E-05	cubic meters
cubic yards	0.7645549	cubic meters
degrees Fahrenheit	(F-32)/1.8	degrees Celsius
feet	0.3048	meters
gallons (US liquid)	3.785412 E-03	cubic meters
gallons per minute	6.309019 E-05	cubic meters per second
inches	0.0254	meters
mils	0.0254	millimeters
pounds (force)	4.448222	newtons
pounds (force) per square inch	6.894757	kilopascals
pounds (mass)	0.45359237	kilograms
pounds (mass) per cubic foot	16.01846	kilograms per cubic meter
pounds (mass) per cubic inch	2.757990 E+04	kilograms per cubic meter
pounds (mass) per square foot	4.882428	kilograms per square meter
pounds (mass) per square yard	0.542492	kilograms per square meter
revolutions per minute	0.10471975	radians per second
square feet	0.09290304	square meters
square inches	6.4516 E-04	square meters
tons (2,000 pounds, mass)	907.1847	kilograms
yards	0.9144	meters

1 Introduction

1.1 Background

Since 2006, researchers at the U.S. Army Engineer Research and Development Center (ERDC) and the U.S. Air Force (USAF) have been conducting research under the USAF's Airfield Damage Repair (ADR) Modernization Program to develop new, expedient pavement repair techniques in an effort to update repair guidance for military airfields. The general objective of the ADR Modernization Program is to update the USAF's ADR capability through development of new ADR solutions that are scalable based on the potential munition threat(s) and/or sustained damage.

ADR encompasses more than simply repairing the damaged pavement and includes seven general phases:

1. Identification of damage sustained to the airfield operating surfaces,
2. Selection of minimum pavement surface areas required to support aircraft operations including the minimum operating strip (MOS) and minimum aircraft operating surface (MAOS),
3. Clearance of unexploded ordnance (UXO) from the MOS/MAOS,
4. Repair of damaged pavement within the selected MOS/MAOS,
5. Installation of aircraft arresting systems,
6. Application of airfield markings and paint stripings, and
7. Restoration of airfield lighting.

All seven phases must be completed within 8 hr from the time of last munition impact. While each phase is critical to the safe launch and recovery of aircraft, the most time consuming phase is the repair of the damaged pavement within the MOS/MAOS (crater repair phase), particularly if the repair scenario requires the completion of a large number (up to 120) of small (8.5 by 8.5 ft) crater repairs. Regardless of the number of required repairs, the repairs must be completed within 3 (objective) to 6.5 (threshold) hr after an attack.

The crater repair phase can be divided into seven general steps or tasks:

1. On-ground crater assessment,
2. Initial debris removal,

3. Upheaved pavement marking,
4. Saw cutting,
5. Excavation,
6. Backfilling, and
7. Capping.

After the on-ground crater assessment, each task is executed by separate teams, each of which should ideally take a similar amount of time for optimal efficiency and a continuous work flow. If one task requires a longer length of time, then the teams performing the subsequent tasks will be required to wait, thus slowing the entire ADR process.

1.1.1 Required capabilities for saw cutting crater repairs

Results combined from previous demonstrations (Priddy et al. 2013a; Priddy et al. 2013b) and evaluations (Bell et al. 2014; Edwards et al. 2015; Bell et al. 2013; Edwards et al. 2013) were used to create the techniques, tactics, and procedures (TTPs) manual describing the processes and requirements of crater repair (Air Force Civil Engineer Center, in preparation). The results indicated that saw cutting around upheaved pavement is often the slowest task of crater repair. The TTPs indicate the goal for completing cutting of pavement around a small crater using two wheel saws should be 22 min or less with a rate of 1 ft/min.

1.1.2 Previous crater repair work

Prior to the 2009 Operational Utility Assessment (OUA) in Avon Park, FL (Priddy et al. 2013b), minimal testing and evaluation of crater repair methods had been conducted in thick pavement surfaces. During the OUA, it was determined that the cutting rates in thick (18-in.) portland cement concrete (PCC) did not meet the required production rates for optimal efficiency and continuous work flow. During this demonstration, cutting in thick PCC was also determined to be more difficult when dowels were present.

In general, the OUA demonstration validated that the new materials, equipment, and procedures are capable of meeting the required ADR threshold timeline of repairs (6.5 hr), and crater repairs using these materials and techniques were determined to be capable of sustaining actual fighter and cargo aircraft traffic (Priddy et al. 2013a; Priddy et al. 2011). Based on the results of the OUA and actual aircraft operations, additional research efforts were conducted under the ADR Modernization Program to refine the crater repair procedures and to identify and/or refine required equipment to achieve the objective repair timeline of 3 hr.

In 2012 and 2013, additional testing was conducted at ERDC in Vicksburg, MS, to determine the most efficient method of saw cutting in 18- and 24-in.-thick PCC by using a variety of equipment as described by Bell et al. (2014) and Edwards et al. (2015). The testing conducted in 2012 (Bell et al. 2014) was in a PCC test section constructed with a PCC paving mixture containing limestone as the coarse aggregate. The testing conducted in 2013 (Edwards et al. 2015) was in a PCC test section constructed with a PCC mixture containing chert as the coarse aggregate. These PCC aggregates were considered the best (limestone)- and worst (chert)-case scenarios for saw cutting based on aggregate hardness. These tests confirmed that both slower cutting times and more bit, or tooth, wear are experienced when saw cutting PCC pavements containing harder aggregates. The saw-cutting rate goal for these investigations was 1 ft/min regardless of PCC thickness or aggregate type. The pieces of equipment were evaluated for both their ability to saw cut minimum depths of 18 and 24 in. and their ability to achieve the minimum cutting rate of 1 ft/min. The rates of wear on the cutting bits/teeth were also measured.

The following summarizes the saw-cutting findings in limestone-based PCC aggregate from the 2012 evaluation (Bell et al. 2014):

- The Caterpillar Sw45 and SW60 wheel saws were capable of cutting a maximum of 18 and 24 in. deep, respectively. However, they cut at their maximum depth only when used in the most efficient manner – with minimal concrete debris buildup under the saw, with the saw level, and with the guard maintained continuously at its lowest position. Generally, the SW45 and SW60 wheel saws effectively cut to maximum depths of 17 and 23 in., respectively.
- The performances of the Caterpillar SW45 and SW60 wheel saws on the 18-in.-thick PCC were similar, and their average production rates met the 1 ft/min goal for saw cutting. On average, the SW45 wheel saw cut approximately 4 percent faster than the SW60 wheel saw in the 18-in.-thick PCC.
- The Husqvarna FS 6600D walk-behind saw was capable of cutting through the grade 60 steel, 1.25- and 2-in.-diam dowel rods in the 18- and 24-in.-thick PCC, respectively. The average production rate

exceeded the 1 ft/min goal for saw cutting. PCC joints containing dowel rods had minimal effect on the walk-behind saw's capability to cut thick PCC.
- The average production rate of the Caterpillar SW60 wheel saw on the 24-in.-thick PCC was slightly less than the goal of 1 ft/min. The SW60 wheel saw was the only option tested for saw cutting 24-in.-thick PCC to full depth.

The following summarizes the saw-cutting findings in chert-based PCC from the 2013 evaluation (Edwards et al. 2015):

- The Caterpillar Sw45 and SW360B wheel saws were not capable of cutting the required depths of 18 and 24 in. deep, respectively. The SW45 and SW360B wheel saws effectively cut to maximum depths of 16.5 and 22.5 in., respectively. The Bradco RS24 wheel saw was also unable to cut to a 24-in. depth; the maximum depth achieved was 22.5 in.
- The Bradco RS24, Caterpillar SW45, and Caterpillar SW360B wheel saws did not meet the saw-cutting goal of 1 ft/min in the 18- or 24-in.-thick PCC.
- The performances of the Caterpillar SW45 and SW360B wheel saws in the 18-in.-thick PCC were similar. On average, the SW360B wheel saw cut approximately 8 percent (0.05 ft/min) faster than the SW45 wheel.
- The Bradco RS24 wheel saw attached to the Caterpillar 279C CTL or Case TV380 CTL was not efficient enough for the ADR scenarios. The average cutting rate of the comparable Caterpillar SW360B wheel saw attached to the Caterpillar 279C CTL (0.61 ft/min) was 2.5 times faster than that of the Brado RS24 wheel saw (0.24 ft/min).
- The Vermeer CC155 with the CC1531 concrete cutter using the Kennametal SM04 teeth was faster than all other evaluated saws. On average, the CC1531 concrete cutter rate of 4.45 ft/min was almost twice as fast as that of the Vermeer RTX1250 tractor with the RW1236W wheel saw (2.31 ft/min) and approximately 7.5 times faster than that of the Caterpillar SW45 and SW360B wheel saws (0.60 ft/min) in the 18-in.-thick PCC. The CC1531 (2.81 ft/min) was approximately twice as fast as the RW1236W (1.49 ft/min) in 24-in.-thick PCC.
- Both CAT 375-7681 and CAT 149-5763 teeth from Caterpillar had similar cutting rates when used with the Caterpillar SW45 wheel saw. The CAT 375-7681 cutting teeth were considered equivalent to the expiring CAT 149-5763 cutting teeth.

- The Kennametal SM04 teeth used on the Vermeer RW1236W and CC1531 saws were the most durable cutting tools tested, followed by the Kennametal RP15 teeth on the Caterpillar SW45 and SW360B saws and then the CAT 375-7681 and CAT 149-5763 teeth on the Caterpillar SW45 and SW360B saws. The Kennametal RP15 cutting bits were equivalent to the Kennametal SM04 bits but with a smaller shank diameter, which was required for the Caterpillar saws.
- The Caterpillar concrete teeth (CAT 227-7340) tested on the Caterpillar SW45 and SW360B wheel saws had the slowest rate and were the least durable. The teeth were able to cut only approximately 7 ft before the carbide tips were completely worn.
- The Kennametal SM08 teeth used on the Vermeer RW1236W wheel saw were able to cut only approximately 16 ft before the carbide tips were completely worn. It is expected that the teeth, or their equivalent, are less durable on the Caterpillar SW45 and SW360B wheel saws.
- The most efficient overcut lengths were 4 to 8 in. long. Shorter overcuts increased the breaking and removal times and ran a greater risk of cracking the parent slab. Longer overcuts decreased the breaking and removal times; however, they increased the saw time and decreased the overall repair quality after capping.

1.2 Objective and scope

The objective of this project was to further investigate improved equipment and to update TTPs for cutting small crater repair boundaries (8.5 by 8.5 ft) in thick PCC pavements. The scope of this work included using various saw-cutting equipment to cut thick PCC pavements containing either limestone or chert coarse aggregate. An undoweled, full-scale test section was constructed of 18- and 24-in.-thick PCC. Various combinations of wheel saw equipment and cutting bits were evaluated to determine the most efficient use of equipment and cutting bit combinations for sawing bomb-damaged pavements. Specifically, the evaluation included measuring saw-cutting rates, cutting bit wear, maneuverability around small craters, and travel speed of the saw technologies.

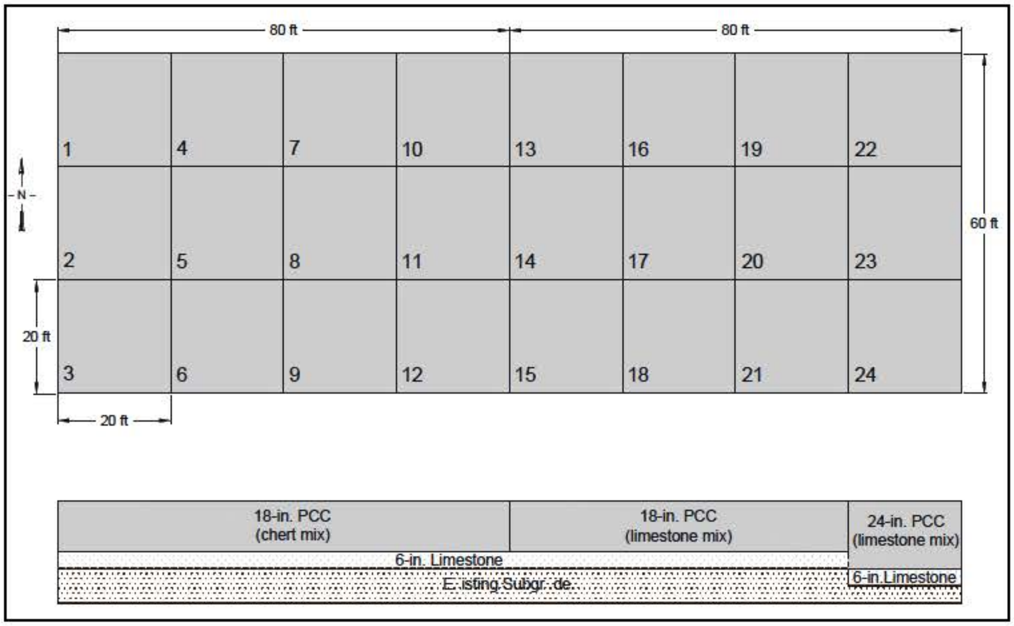
This report provides information for the following:

1. Specification of required capabilities for saw cutting crater repairs,
2. Description of test site,
3. Description of evaluated equipment, and
4. Testing matrix and field evaluation results.

2 Test Section Description and Characterization

A full-scale test section was constructed in March 2014 and consisted of 18- and 24-in.-thick PCC to provide a testing area for evaluating a variety of concrete sawing equipment for crater repairs. The test section was located on a pavement test area at ERDC. The plan and profile views of the test section are shown in Figure 1. The slabs were numbered to identify the slab locations used for the various saw tests.

Figure 1. Plan and profile views of test section.



The test section was constructed of two different PCC mixtures – one using limestone as the coarse aggregate and one using chert as the coarse aggregate. These two aggregate types were selected to represent the best (limestone)- and worst (chert)-case scenarios for saw cutting due to their hardness. By definition, hardness is the abrasion resistance of aggregate, which is usually measured using the Mohs scale. The Mohs scale is a numerical scale ranging from 1 (talc) to 10 (diamond), with 10 being the hardest. Chert is considered a critically hard aggregate and usually measures as an 8 or 9 on the Mohs scale, while limestone is a medium soft to medium aggregate measuring from 2 to 4 on the scale (Esch

Construction Supply, Inc. 2014). Harder aggregates require more cutting effort and result in more and faster wear on blades and cutting bits.

2.1 Test site preparation

The existing subgrade, composed of mostly silt with some gravel, was leveled prior to construction with a 0.4 percent grade to allow for drainage. A drainage ditch was also constructed off the north central side of the section. The base layer consisted of 6 in. of compacted 610 crushed limestone. The crushed limestone was compacted to a target of 95 percent modified Proctor density or to the point that in-place density did not increase with additional compactive effort. A Caterpillar CS433E vibratory smooth drum roller and a Wacker WP 1550W plate compactor were used for compaction (Figure 2).

Figure 2. Compacting crushed limestone base material.

2.2 Material characterization

The limestone base layer material was characterized during construction using the Troxler nuclear density gauge (American Society for Testing and Materials (ASTM) D6938) (2010c) and the dynamic cone penetrometer (DCP)(ASTM D6951)(2003). Figure 3 shows DCP testing on the base material on the western half of the test section. Survey data were collected every 20 ft along the length of the test section and every 20 ft along the width of the test section of each pavement layer to ensure the desired layer thicknesses were achieved (Figure 4).

Figure 3. DCP testing.

Figure 4. Surveying base layer.

Table 1 presents the results of the nuclear density gauge tests on the limestone base. The base was tested with the nuclear density gauge at 15 different test points for a total of 30 tests. The gauge was turned 90 deg at each test location for a second measurement at the same test point. Test results for the crushed limestone showed an average dry density of 134.2 lb/ft^3 and an average moisture content of 5.6 percent.

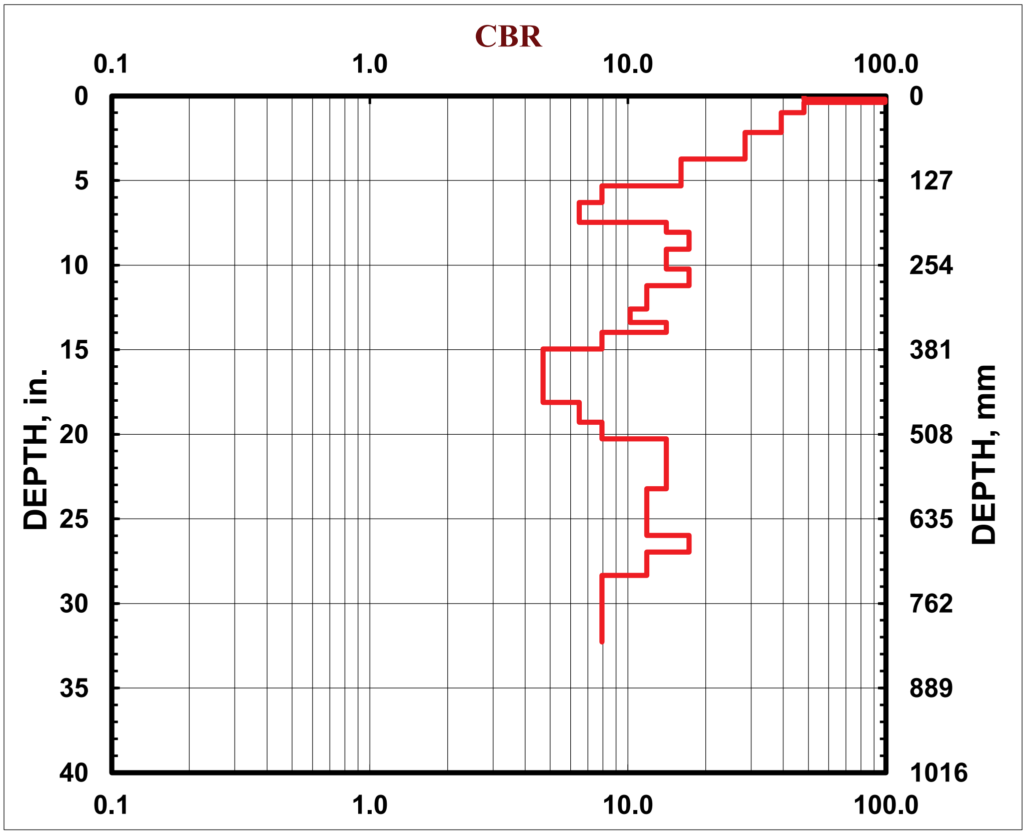
Table 1. Nuclear density gauge results for crushed limestone base material.

Test Number	Wet Density (pcf)	Moisture (pcf)	Dry Density (pcf)	Moisture (%)
1	141.0	6.9	134.1	5.1
	140.9	6.6	134.3	4.9
2	141.0	7.3	133.6	5.5
	143.4	6.8	136.6	5.0
3	141.0	6.4	134.6	4.7
	131.2	6.4	124.9	5.1
4	143.2	7.7	135.5	5.7
	147.2	8.3	138.9	5.9
5	145.2	7.4	137.9	5.4
	144.8	7.4	137.4	5.4
6	140.8	8.0	132.8	6.0
	142.9	7.9	135.0	5.9
7	147.4	8.3	139.0	6.0
	148.2	8.3	139.9	5.9
8	145.5	7.4	138.1	5.4
	149.3	7.9	141.4	5.6
9	136.6	7.0	129.7	5.4
	138.7	4.9[a]	132.3	6.5
10	142.3	8.1	134.2	6.0
	141.5	8.5	133.0	6.4
11	145.2	8.4	136.7	6.2
	145.8	7.8	138.0	5.7
12	139.2	6.9	132.3	5.2
	138.7	6.6	132.1	5.0
13	140.1	7.7	132.4	5.8
	138.8	7.5	131.3	5.7
14	139.5	7.2	132.3	5.5
	137.5	6.8	130.7	5.2
15	141.0	8.8	132.3	6.6
	133.0	7.8	125.1	6.3

[a] Possible outlier; data excluded from average.

The DCP was used to estimate the strength of the subgrade layer by testing from the top of the compacted crushed limestone base material into approximately 20 in. of the existing subgrade. The average California Bearing Ratio (CBR) of the silty subgrade material was 10. Figure 5 presents a DCP test result showing the variable strength of the crushed limestone base layer (first 6 in.) and the strength of the silty subgrade.

Figure 5. Representative DCP result of base and subgrade materials.



The DCP was not able to accurately estimate the strength of the limestone base layer due to lack of confinement at the top of the testing layer. For a coarse-grained material such as the limestone base used in the test section, Webster et al. (1994) determined that a 5-in.-minimum penetration depth was required before the actual strength of the surface soil layer could be determined with the DCP. Thus, the DCP could not be used to accurately estimate the base's strength because the material was only 6 in. thick. The CBR of the crushed limestone material was assumed to be between 80 and 100 based on the dry density results from the nuclear density gauge on the material and previous experiences of the authors with this material.

2.3 PCC construction

The PCC pavement was constructed on two different days during March 2014 of an airfield-quality concrete designed to meet minimum flexural strength requirements for airfield PCC of 650 psi or 5,000 psi unconfined compressive strength (UCS). Twenty-one slabs were 18 in. thick, and three slabs were 24 in. thick; each slab was 20 by 20 ft. The slab dimensions were in accordance with maximum Department of Defense (DoD) joint spacing specifications prescribed in UFC 3-260-02 for PCC airfield pavements greater than 12 in. thick (DoD 2001).

The PCC test section consisted of two different PCC mixtures. The western half of the test section (placed on day 1) was produced using a local PCC mix design capable of achieving a minimum 5,000 psi UCS after 28 days of cure that utilized chert gravel as the coarse aggregate. The eastern half (placed on day 2) was produced using a local PCC mix design also capable of achieving a minimum 5,000 psi UCS after 28 days of cure, but utilized limestone as the coarse aggregate. As shown in previous research efforts (Bell et al. 2013, Edwards et al. 2015), differences in the hardness of the coarse aggregates used in the PCC mixures impacted the durability and efficiency of saw-cutting equipment. Thus, two PCC mix aggregates, limestone (best case) and chert (worst case), were used to evaluate the saws' durabilities and efficiencies and to compare these results to those obtained during the previous saw-cutting research efforts in similar PCC pavements. The PCC was placed using a pump truck, consolidated with 2-in. spud vibrators, and screeded with a self-powered, vibratory truss screed. Figures 6, 7, and 8 show the PCC construction process.

During placement, test specimens were prepared in accordance with ASTM C39 (2010a) for compressive cylinders and ASTM C78 (2010b) for flexural beams. A maximum slump of 7 ± 1 in. for the delivered PCC was specified to allow the PCC to be pumped. Figure 9 shows beams being cast and the PCC slump being measured. Average laboratory data for each PCC mixture are included in Table 2. The strengths of the PCC exceed the 5,000 psi UCS and 650 psi flexural strength requirements generally specified for PCC airfield pavements. The average of the measured slumps for the western and eastern PCC pours were 7 and 7.5 in., respectively.

Figure 6. Installing steel forms around perimeter of test section.

Figure 7. Placing PCC via pump truck.

Figure 8. Screeding PCC by using vibratory truss screed.

Figure 9. Casting PCC beams and measuring PCC slump.

Table 2. Average laboratory PCC data.

PCC Mix	Modulus (ksi)		UCS (psi)		Flex Strength (psi)	
	28-Day	90-Day	28-Day	90-Day	28-Day	90-Day
Chert aggregate	6,100	6,500	6,300	6,900	860	890
Limestone aggregate	6,100	6,700	6,100	7,100	785	920

The PCC section was completed with a light broom finish, coated with an acrylic curing and sealing compound meeting ASTM C309-11 (2011) specifications, and then saw cut to provide transverse and longitudinal joints. The 18- and 24-in.-thick sections were saw cut to a depth of 2 in. soon after the PCC was finished. The remaining 3- and 4.5-in. joint cut depths for the 18- and 24-in.-thick PCC slabs, respectively, were completed the mornings following PCC placement.

3 Evaluated Technologies

Various equipment and tools were assessed to determine whether the saw-cutting speed in 18- and 24-in.-thick airfield-quality PCC could be increased to reduce crater repair timelines. The Ditch Witch RT120 Quad tractor equipped with the H1140 saw and the Sandvik F203 and F286 concrete cutting bits were the newly evaluated technologies included in this test. All other technologies were evaluated in previous ADR tests and demonstrations (Priddy et al. 2013a; Priddy et al. 2013b; Edwards et al. 2015; Bell et al. 2014; Edwards et al. 2013; Bell et al. 2013). All equipment and cutting bits used in this test effort are described in this chapter.

3.1 Equipment

3.1.1 Caterpillar 279C compact track loader

Caterpillar 279C compact track loaders (CTL), or skid steers, are high-flow, rubber-tracked machines with quick disconnect fittings that are used for numerous tasks in the current ADR crater repair TTPs (Figure 10). The quick disconnect feature allows attachments to be rapidly switched without the use of tools. These multi-purpose machines are employed for many of the ADR processes, including rapidly cutting around the upheaval of bomb-damaged pavement (repair area boundaries) with wheel saw attachments, breaking pavement with the hammer attachment, removing debris with bucket attachments, screeding pelletized asphalt repair caps with the asphalt screed attachment, and clearing of dust and debris with the broom attachment. Specifications for the machines are in Table 3.

3.1.2 Caterpillar SW45 and SW60 wheel saw attachments

The Caterpillar CTLs are equipped to operate the Caterpillar SW45 (Figure 11) or SW60 wheel saw attachments. These wheel saw attachments produce 3.5-in.-wide cuts. The SW45 has an 18-in.-maximum depth cut, and the SW60 has a 24-in.-maximum depth cut. Commercial off-the-shelf SW60 models have a 6-in.-wide blade, but the cut is too wide for the purposes of the ADR program. The SW60 was modified for ERDC to provide a 3.5-in.-wide cut. The ERDC-modified SW60 is equivalent to Caterpillar's SW360B wheel saw. Specifications for the SW45 and the modified SW60 machines are shown in Table 4.

Figure 10. Caterpillar 279C CTL.

Table 3. Caterpillar 279C CTL specifications.

Parameter Specifications	CAT 279C CTL
Net power	82 hp
Operating weight	9,495 lb
Rated operating capacity	3,200 lb at 50% tipping load
Travel speed	5.0 mph
Tipping load	6,483 lb
Breakout force, tilt cylinder	7,308 lb
Maximum loader hydraulic pressure*	4,061 psi
Maximum loader hydraulic flow*	33 gal/min

*for high-flow XPS models

Figure 11. Caterpillar SW45 wheel saw attachment.

Table 4. Caterpillar SW45 and SW60 wheel saw specifications.

Parameter Specifications	CAT SW45	Modified CAT SW60
Overall width	71 in.	74 in.
Overall height	57 in.	69 in.
Length	78 in.	88 in.
Weight	2,295 lb	2,750 lb
Wheel width (without teeth)	3 in.	3 in.
Hydraulic flow requirement	24 - 42 gpm	26 - 42 gpm
Optimal hydraulic pressure range	2,611 - 4,351 psi	2,611 - 4,351 psi
Wheel torque at maximum pressure	4,944 ft-lb	5,931 ft-lb
Wheel speed at maximum flow	115 rpm	96 rpm
Number of teeth	64 per wheel	70 per wheel
Maximum depth of cut	18 in.	24 in.
Sideshift travel	26 in.	26 in.

3.1.3 Wheel saw targets and rulers for Caterpillar SW45 and SW60

The combined use of wheel saw targets positioned near the repair areas and the placement of rulers on the Caterpillar wheel saws eliminate the need for extra spotters and decrease the potential for excessive overcuts during the saw cutting of crater repairs. Overcut lengths are the amount of PCC sawed beyond the marked corners of a crater repair area. The saw target system was developed during previous field testing efforts (Edwards et al. 2015) using the Caterpillar SW45 and SW60 wheel saws in 18- and 24-in.-thick PCC.

The saw target system (Figure 12) consists of four parts: (1) alignment guide for the top of the wheel saw, (2) end target stand, (3) rulers adhered to the wheel saw, and (4) magnetic arrows above the rulers. The alignment guide is a rookie pole attached with a small metal plate and two bolts in the small opening at the top front of the wheel saw. The rookie pole is a flexible, strong fluorescent orange plastic pole normally used on larger vehicles for greater visibility and safety. The rookie pole is 0.75 in. in diameter and 24 in. long. The metal plate specifications and placement are shown in Figure 13. The end target stand consists of a T-shaped base made of 2- by 2-in.-square steel tubing (0.1875-in. wall thickness) that is 18 in. wide and 18 in. long (Figure 14). A threaded 0.5-in.-diam aluminum pipe 47.75 in. tall is screwed into the base. The inner diameter of the aluminum pipe is machined to 0.75 in. and a depth of 2 in. to hold the rookie pole (Figure 15).

Rulers are printed on self-adhesive vinyl and placed on the sides of the wheel saws to assist with wheel saw positioning. A ruler is placed on the wheel saw such that the 0-in. mark lines up with the right side of the fixed bar on the left side of the saw. The right side of the fixed bar is 19 in. from the back of the saw, as seen in Figure 16. Ruler placement on the right side of the saw is 19 in. from the back of the saw; a ruler with the numbers in reverse order is required.

The magnetic arrow is placed at the desired location and is used by the spotter to determine where to position the saw prior to cutting. The arrow on the wheel saw is aligned with the edge of the crater repair when the wheel saw is parallel to the ground. The end saw target is placed at the desired distance away from the edge of the crater repair. The locations of the arrow and end target depend on the desired overcut lengths, as discussed later in this report. The CTL operator uses the rookie pole alignment guide on the wheel saw to line up with the end target placed by the wheel saw spotter (Figure 17). Once the wheel saw attachment bumps the target, the cut is complete.

Figure 12. Wheel saw target setup (Edwards et al. 2015).

Rookie pole alignment guide

Arrow is placed on the ruler and aligned with the crater edge.

End target is placed at a specified distance from the crater edge.

Figure 13. Specifications for metal plate attachment piece for alignment guide attached to top of wheel saw (Edwards et al. 2015).

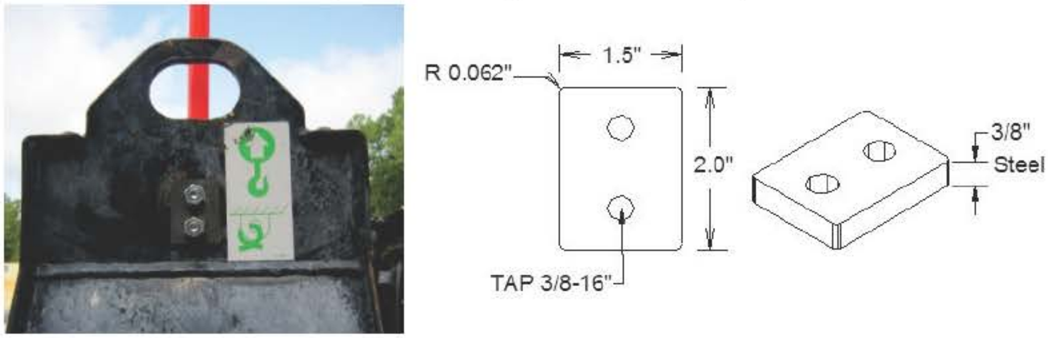


Figure 14. Specifications for the end target stand (Edwards et al. 2015).

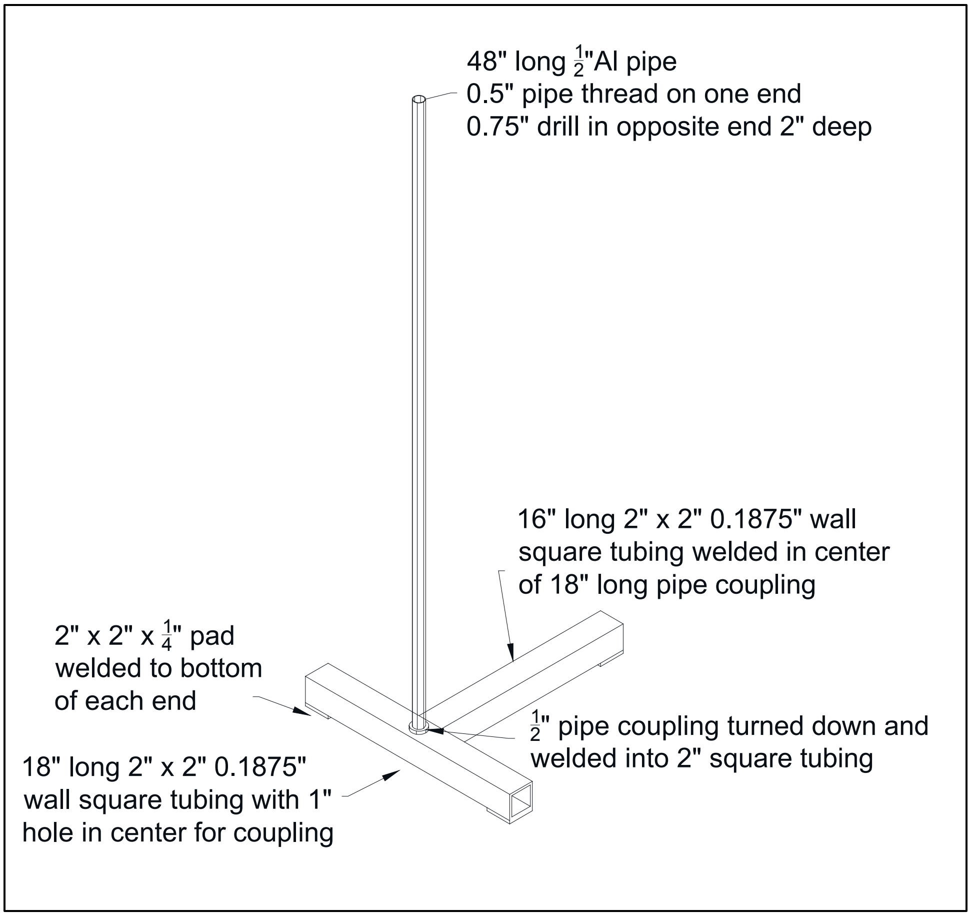


Figure 15. Specifications for the end target stand parts (Edwards et al. 2015).

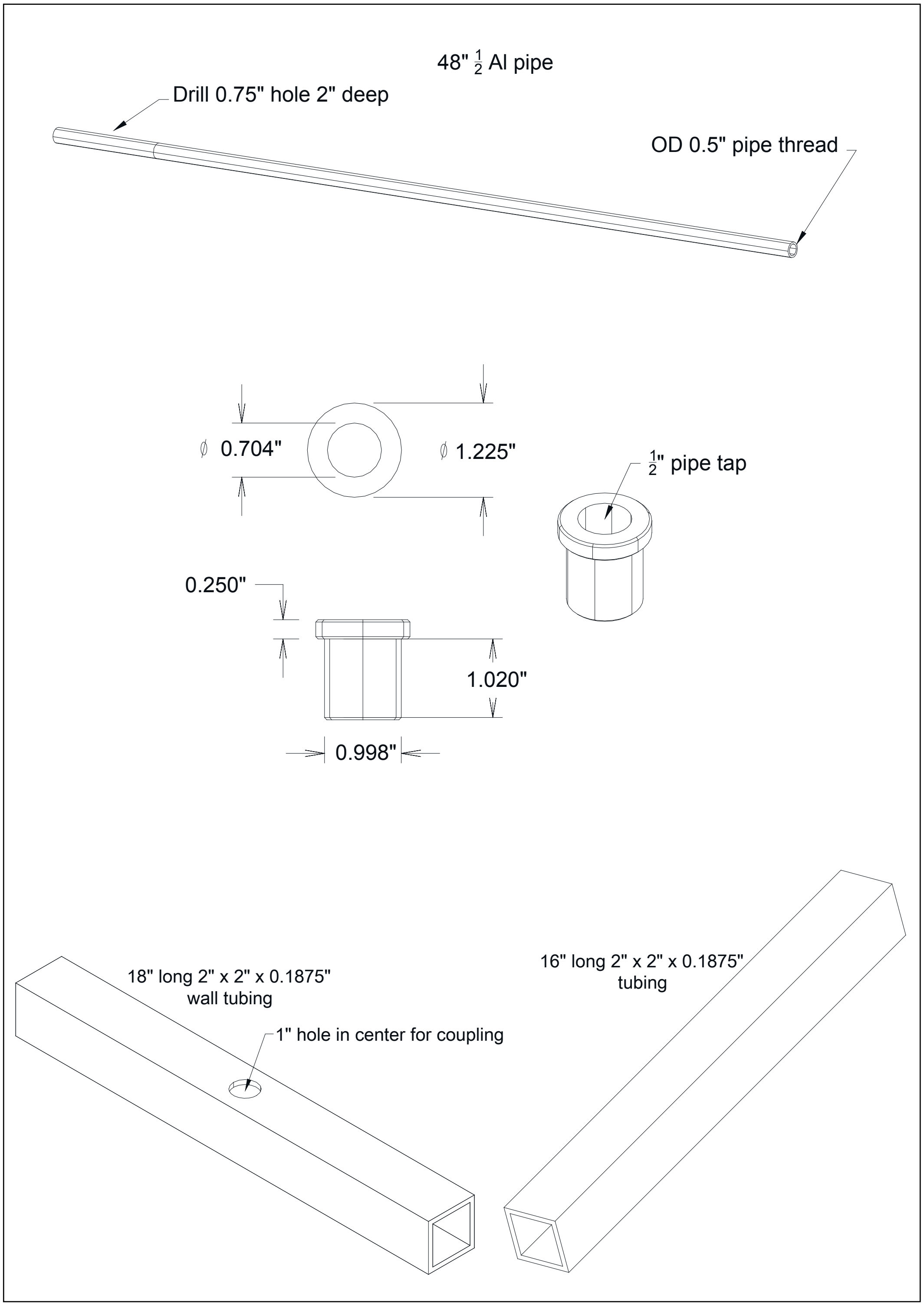
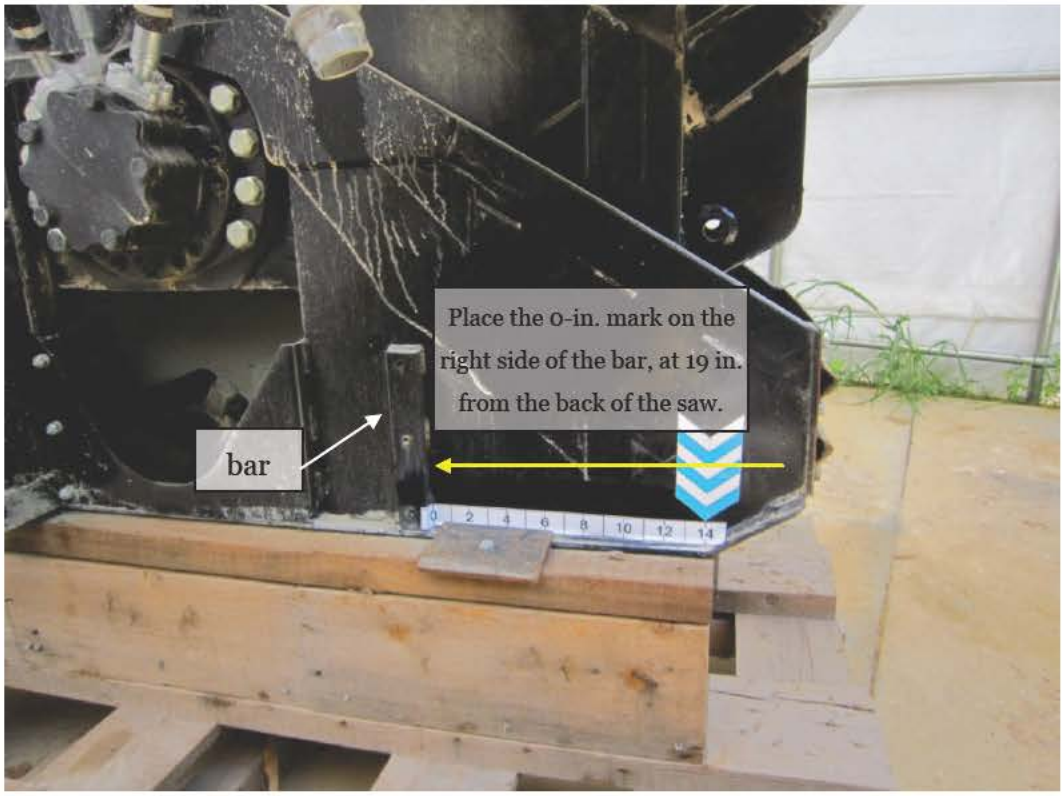


Figure 16. Ruler on wheel saw (Edwards et al. 2015).



Place the 0-in. mark on the right side of the bar, at 19 in. from the back of the saw.

Figure 17. Using the rookie stick to line up to edge of crater (Edwards et al. 2015).

3.1.4 Vermeer CC155 concrete cutter with CC1531 wheel

The Vermeer CC155 machine is equipped with the CC1531 concrete cutter wheel (Figure 18). The wheeled machine has a cab for the operator and can perform wet or dry cuts. Two water tanks with a total capacity of 200 gal are mounted on the machine. The water is optional and can be used to suppress dust and to keep the cutting teeth from overheating. The CC1531 concrete cutter wheel is mounted near the center of the machine as opposed to being an attached arm. The concrete cutter makes a 5.5-in.-wide cut. Table 5 presents the specifications of the concrete cutter with the wheel.

3.1.5 Vermeer RTX1250 tractor

The Vermeer RTX1250 tractor (Figure 19) can switch between rubber tires and a rubber quad-track system. The rubber tracks were used for the reported evaluation. Although this evaluation included the tractor with no cab, there is an optional cab for the machine to protect the operator from concrete dust and precipitation. The RTX1250 has optional attachments including a reel carrier, a plow, a rockwheel, a trencher, a backhoe, and a backfill blade. Table 6 lists some key specifications of the tractor.

Figure 18. Vermeer CC155 concrete cutter with CC1531 wheel.

Table 5. Vermeer CC155 with CC1531 specifications.

Parameter Specifications	Vermeer CC155
Gross power	155 hp
Overall width	96 in.
Overall height	120 in.
Length	165 in.
Weight (water tanks empty)	22,800 lb
Weight (water tanks full)	24,600 lb
Wheel diameter	84 in.
Wheel width (without teeth)	2 in.
Turning radius	18 ft
Max transport speed	10 mph or 900 ft/min
Number of teeth	90 per wheel
Maximum depth of cut	31 in.

Figure 19. Vermeer RTX1250 tractor with RW1236W rockwheel attachment.

Table 6. Vermeer RTX1250 tractor specifications.

Parameter Specifications	Vermeer RTX1250
Gross power	120 hp
Height	109 in.
Width	93 in.
Length	161 in.
Weight	13,620 lb
Max torque	350 ft-lb
Max transport speed	9 mph
Turning radius	20 ft

3.1.6 Vermeer RW1236W rockwheel

The RW1236W rockwheel attachment (Figure 19) is used on the Vermeer RTX1250 tractor for trenching or sawing through concrete. The center-mounted wheel is pulled behind the operator. The RW1236W makes a 5-in.-wide cut. Specifications for the machine are shown in Table 7.

Table 7. Vermeer RW1236W rockwheel specifications.

Parameter Specifications	Vermeer RW1236W
Length	89 in.
Weight (without teeth and segments)	4,260 lb
Wheel diameter	88 in.
Number of teeth	90 per wheel
Maximum depth of cut	36 in.

3.1.7 Ditch Witch RT120 Quad tractor

The Ditch Witch RT120 Quad utility tractor (Figure 20) is similar to the Vermeer RTX1250 with its rubber quad-track system. The diesel-fueled machine has an optional driver’s cab and a color LCD display that provides engine and diagnostic information to the operator. Optional attachments such as trenchers, plows, backhoes, a reel carrier, and saws can be used with the RT120 Quad. Table 8 presents the key specifications for the machine.

3.1.8 Ditch Witch H1140 wheel saw

The Ditch Witch H1140 saw can be attached to the RT120 Quad tractor and is used for trenching or sawing through pavement. Figure 20 shows the H1140 wheel saw on the RT120 Quad tractor. The saw model makes 4.5-, 6-, and 8-in.-wide cuts; the saw evaluated for this project was the 4.5-in.-wide model. Table 9 shows the main specifications of the H1140 saw.

Figure 20. Ditch Witch RT120 Quad with H1140 rock saw.

Table 8. Ditch Witch RT120 Quad tractor specifications.

Parameter Specifications	Ditch Witch RT120 Quad
Gross power	121 hp
Height	117 in.
Width	89 in.
Length	166 in.
Weight	13,600 lb
Max transport speed	7.2 mph

Table 9. Ditch Witch H1140 saw specifications.

Parameter Specifications	Ditch Witch H1140
Length	124 in.
Weight (without teeth and segments)	5,900 lb
Number of teeth	70 per wheel
Maximum depth of cut	40 in.

3.2 Wheel saw-cutting tools

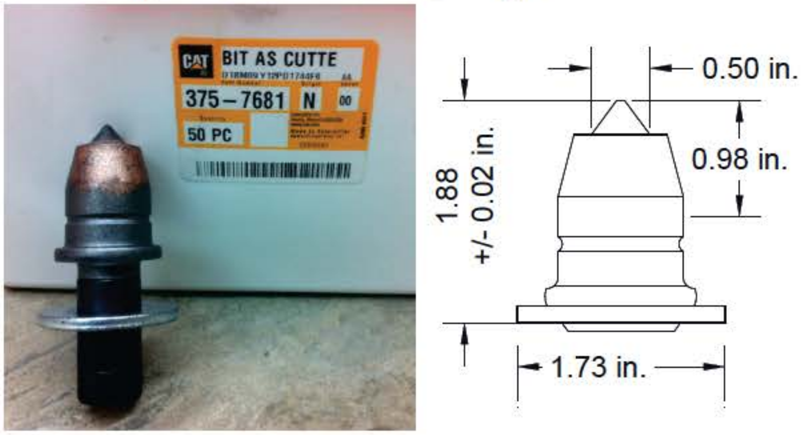
Conical tools are used on the wheel saws and wheel saw attachments for cutting into the pavement. Various teeth are available for varying needs and jobs. Most teeth are made of steel with carbide tips. The carbide may be produced as a seat tip or an insert tip. Replacing teeth is necessary when the carbide bits become worn, particularly after cutting through PCC. A punch tool is used with a mallet and/or puller to remove the teeth, and the teeth are tapped into place with the mallet, as shown in Figure 21. Another option for installing teeth is to use an air hammer. The following sections describe the cutting teeth evaluated during this study.

Figure 21. Replacing teeth on a Vermeer RW1236W saw.

3.2.1 Caterpillar cutting tools (375-7681)

The Caterpillar 375-7681 cutting tools (Figure 22) are primarily used on cold planer equipment but are also designed for use in all Caterpillar wheel saws. The teeth are made of carbide tungsten and forged steel and have a 0.78-in.-diam shank. The shank is the cylindrical shaft that is housed inside the wheel saw shoe.

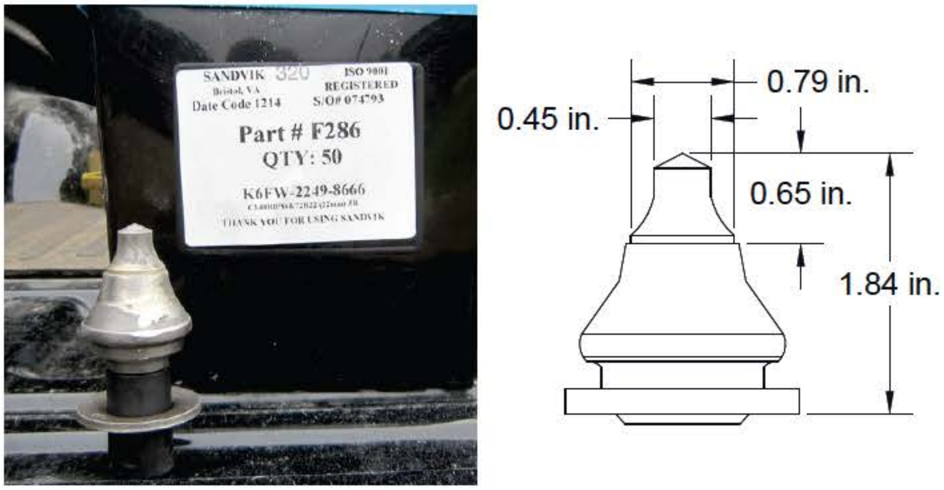
Figure 22. Wheel saw tooth, Caterpillar 375-7681.



3.2.2 Sandvik cutting tools (F286)

The 0.86-in.-diam Sandvik F286 cutting tool has a conical valve-seat carbide tip. The carbide tip, as opposed to a carbide insert, allows for good penetration and protects steel wash. The tools are best suited for use in soft to medium-hard materials or conditions. Figure 23 shows a picture and diagram of the Sandvik F286 cutting tooth.

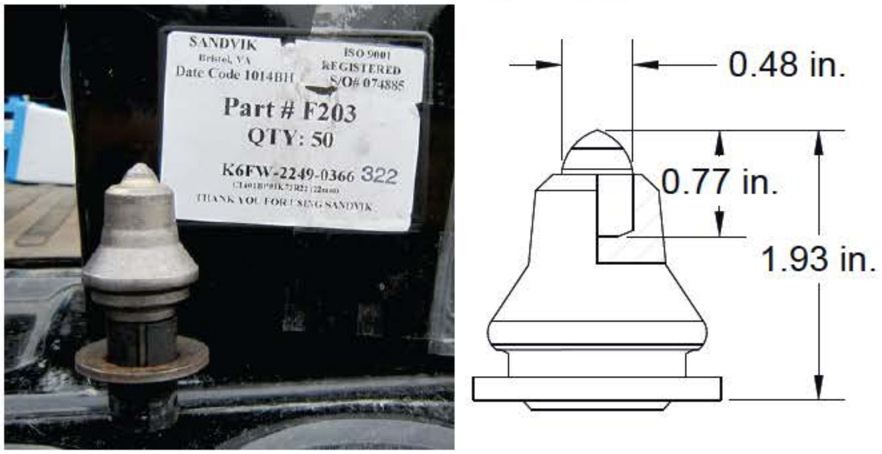
Figure 23. Wheel saw tooth, Sandvik F286.



3.2.3 Sandvik cutting tools (F203)

The Sandvik F203 trenching tooth is an insert carbide tip, which is most suitable for use in high-impact conditions. The trenching tooth has a forged steel shank that is 0.86 in. in diameter. Figure 24 presents a diagram and a picture of the tooth.

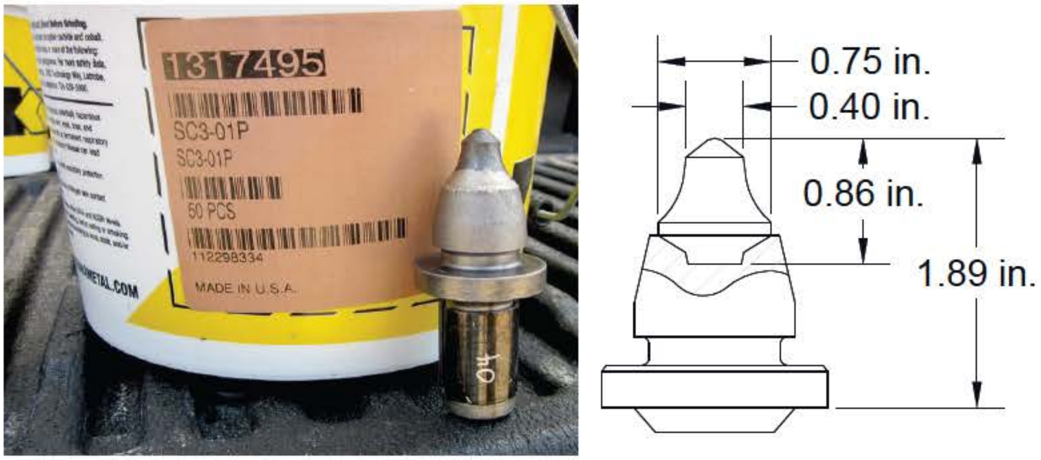
Figure 24. Wheel saw tooth, Sandvik F203.



3.2.4 Kennametal cutting tools (SM04)

The Kennametal SM04 cutting tools are made of forged steel with tungsten carbide tips and have a 0.86-in.-diam shank. The teeth are similar in design to the Sandvik F286 teeth. The teeth are made for cutting through hard asphalt and concrete or in semi-rocky conditions (soft, medium, or abrasive rock). Figure 25 shows a diagram and a picture of the SM04 tooth.

Figure 25. Wheel saw tooth, Kennametal SM04.



3.2.5 Kennametal cutting tools (RP15)

The Kennametal RP15 teeth have a 0.76-in.-diam shank. The cutting tools are made of forged steel with tungsten carbide tips. They are equivalent to the Kennametal SM04 teeth and Sandvik F286 teeth except that the RP15 teeth have a smaller shank diameter. Common applications for these cutting tools on medium- to high-horsepower machines include hard to medium asphalt and concrete conditions. Figure 26 shows a diagram and a picture of the RP15 tooth.

Figure 26. Wheel saw tooth, Kennametal RP15.

4 Field Evaluation and Results

4.1 Field evaluation

The crater repair saw technologies were evaluated from April to July 2014. Various tests were conducted on the PCC test section including the evaluation of teeth wear on each machine, saw-cutting rates, reposition rates, and overcut lengths. The variables were tested by sawing marked 10-ft-long lines inside a slab or around an approximate 8.5- by 8.5-ft square (typical of small crater repairs) marked inside the center of the slab. Teeth wear, saw-cutting rates, and overcut lengths were evaluated in the slabs with the straight cut lines. Teeth wear, saw-cutting rates, reposition rates, and overcut lengths were evaluated in the slabs with the 8.5-ft cut square.

All events were timed to the second. Each method or technology was tested multiple times to obtain average results. The operators varied from inexperienced to highly trained for most equipment. In the current ADR TTPs, the goal for the saw-cutting rate is 1 ft/min or faster (Air Force Civil Engineer Center, in preparation).

The key part of this project was to identify the most effective and efficient saw and cutting bit technologies for small crater repairs. Five saws - the Caterpillar SW45 wheel saw, the Caterpillar SW60 wheel saw, the Vermeer RW1236W rocksaw, the Vermeer CC1531 rocksaw, and the Ditch Witch H1140 saw - were evaluated for their efficiency and maneuverability of cutting around small craters. Five types of teeth - the Caterpillar 375-7681, the Kennametal RP15, the Kennametal SM04, the Sandvik F286, and the Sandvik F203 - were alternated on the five saws. The teeth were replaced after each test set. Table 10 identifies the saw-cutting matrix used for the equipment assessments in the 18- and 24-in.-thick PCC.

Table 10. PCC saw-cutting test matrix.

Test No.	Crater No.	PCC Thickness (in.)	PCC Mix	Saw	Machine	Test	Teeth
1	9	18	chert	CAT SW45	CAT 279C	rate	Kenn RP15
2	17	18	limestone	CAT SW45	CAT 279	rate, reposition	Kenn RP15
3	9	18	chert	CAT SW60	CAT 279C	rate	Kenn RP15
4	18	18	limestone	CAT SW45	CAT 279C	rate	Kenn RP15
5	22	24	limestone	CAT SW60	CAT 279C	rate	Kenn RP15
6	23	24	limestone	Verm RW1236W	Verm RTX1250	rate	Kenn SM04

Test No.	Crater No.	PCC Thickness (in.)	PCC Mix	Saw	Machine	Test	Teeth
7	4	18	chert	Verm RW1236W	Verm RTX1250	rate, reposition	Kenn SM04
8	12	18	chert	Verm RW1236W	Verm RTX1250	rate	Kenn SM04
	2						
9	19	18	limestone	Verm RW1236W	Verm RTX1250	rate, reposition	Kenn SM04
10	15	18	limestone	Verm RW1236W	Verm RTX1250	rate	Kenn SM04
11	8	18	chert	CAT SW45	CAT 279C	rate	CAT 375-7681
12	10	18	chert	CAT SW45	CAT 279C	rate	CAT 375-7681
13	16	18	limestone	CAT SW60	CAT 279C	rate	CAT 375-7681
14	24	24	limestone	Verm CC1531	Verm CC155	rate	CAT 375-7681
15	21	18	limestone	Verm CC1531	Verm CC155	rate, reposition	Kenn SM04
16	13	18	limestone	Verm CC1531	Verm CC155	rate	Kenn SM04
17	6	18	chert	Verm CC1531	Verm CC155	rate	Kenn SM04
18	7	18	chert	Verm CC1531	Verm CC155	rate	Kenn SM04
19	2	18	chert	CAT SW60	CAT 279C	rate	CAT 375-7681
20	11	18	chert	CAT SW60	CAT 279C	rate	CAT 375-7681
21	22	24	limestone	CAT SW60	CAT 279C	rate	Kenn RP15
	23						
22	22	24	limestone	CAT SW60	CAT 279C	rate	CAT 375-7681
	23						
	24						
	22						
23	16	18	limestone	CAT SW45	CAT 279C	rate	CAT 375-7681
	18						
24	14	18	limestone	CAT SW60	CAT 279C	rate	Kenn RP15
25	15	18	limestone	DW H1140	DW RT120 Quad	rate	Sand F203
	17						
	21						
26	21	18	limestone	DW H1140	DW RT120 Quad	rate	Sand F286
	19						
27	9	18	chert	H1140	RT120 Quad	rate	F286
28	9	18	chert	H1140	RT120 Quad	rate	F203
29	9	18	chert	H1140	RT120 Quad	rate	SM04

The Caterpillar and Vermeer saws were also studied to identify the appropriate lineup and stop locations to achieve the desired overcut lengths. Edwards et al. (2015) recommends overcut lengths of 4 to 8 in. Long overcuts (> 8 in.) affect the saw times and the repair quality, while short overcuts (< 4 in.) run the risk of damaging the parent slab during the remaining repair processes of breaking and removing (Edwards et al. 2015). The Ditch Witch saw was not originally included in the test plan, so mechanisms to achieve appropriate overcut lengths using the machine were not determined.

4.2 Field evaluation results

4.2.1 Saw-cutting rates

The results of the sawing evaluation in the 18- and 24-in.-thick PCC are presented in Table 11. The results include the average cutting rates for each equipment tested with the five types of teeth. The average time to reposition to the second cut in a simulated crater is included for the Caterpillar SW45 and Vermeer saws. Reposition times for the Caterpillar SW60 saw were not measured. Previous testing has shown that the Caterpillar SW45 and SW60 wheel saws have similar reposition times since they utilize the same prime mover (Edwards et al. 2015). The Ditch Witch H1140's average reposition time was also not assessed due to its late inclusion to the scope of the project; however, it is assumed that the average time is similar to that of the Vermeer RW1236W saw since both machines are similar in size. All saws were able to consistently cut straight lines.

Table 11 shows that the average saw-cutting rates in the limestone PCC were consistently faster than those in the chert PCC. The average difference between the rates was 57 percent. This is not surprising as chert is much harder and more abrasion resistant than limestone. The Vermeer CC1531 with Kennametal SM04 teeth and Ditch Witch H1140 with Sandvik F286 teeth had the closest rates between the two types of PCC with only 15 percent and 13 percent difference, respectively. Although the saw's cutting teeth have an effect on the cut rate, the relationship is not included in this section; results and discussion relating teeth wear and saw rates are included in Section 4.2.4.

Both Vermeer saws had the fastest rates of any evaluated saws in both the limestone and chert aggregate PCC. The Vermeer saws were evaluated with only the Kennametal SM04 teeth. The CC1531 (4.51 ft/min) was 2.5 times faster than the RW1236W (1.78 ft/min) in the 18-in.-thick chert PCC and was, on average, about twice as fast as the RW1236W in the 18- and 24-in.-thick limestone PCC. Still, the Vermeer RW1236W had a faster cut rate than the Caterpillar and Ditch Witch wheel saws.

Table 11. Saw-cutting production rate results.

Machine	Saw	PCC Thickness (in.)	PCC Mix Agg.	Cutting Teeth	Avg. Plunge Time (min)	Avg. Cut Rate (ft/min)	Avg. Reposition Time (min)
CAT 279C CTL	CAT SW45	18	chert	CAT 375-7681	6.91	0.50	0.94
				Kenn RP15	8.01	0.41	
			limestone	CAT 375-7681	7.18	0.62	
				Kenn RP15	4.88	0.83	
CAT 279C CTL	CAT SW60	18	chert	CAT 375-7681	8.51	0.47	-----
				Kenn RP15	8.82	0.46	
			limestone	CAT 375-7681	5.97	0.72	
				Kenn RP15	6.85	0.84	
		24		CAT 375-7681	8.23	0.49	
				Kenn RP15	6.04	0.64	
Vermeer RTX1250	Vermeer RW1236W	18	chert	Kenn SM04	4.18	1.78	1.85
			limestone		2.08	3.21	
		24			5.62	1.62	
Vermeer CC155	Vermeer CC1531	18	chert	Kenn SM04	1.24	4.51	1.29
			limestone		1.19	5.18	
		24			1.95	3.47	
Ditch Witch RT120 Quad	Ditch Witch H1140	18	limestone	Sand F203	4.55	1.46	----
				Sand F286	3.61	1.94	
			chert	Sand F203	6.62	0.79	
				Sand F286	----	1.71	
				Kenn SM04	5.65	0.70	

The Ditch Witch H1140 wheel saw equipped with the Sandvik F203 and F286 and Kennametal SM04 teeth had the second fastest rate in both the limestone and chert aggregate PCC. The wheel saw was not able to meet the goal of 1 ft/min in the chert aggregate PCC with the Sandvik F203 and Kennametal SM04 cutting tools. The Ditch Witch H1140 saw was not evaluated in the 24-in.-thick PCC due to rapid teeth wear in the 18-in.-thick PCC. The Ditch Witch saw-cutting rates were more efficient than those of the Caterpillar saws; however, only one cut rate was able to be recorded for the H1140 saw for each set of teeth in the chert aggregate PCC because the teeth wore rapidly. The tests were stopped prematurely due to the worn teeth; however, a cut rate was established. More information about the teeth wear is presented in Section 4.2.4.

The Caterpillar SW45 and SW60 saw-cutting rates were comparable in both the limestone and chert aggregate PCC. Similar rates between the two saws were also measured in previous evaluations (Bell et al. 2014; Edwards et al. 2015). The cut rates for the SW45 and SW60 with the Caterpillar 375-7681 teeth and the Kennametal RP15 teeth in the chert aggregate PCC ranged from 0.31 to 0.70 ft/min and averaged 0.46 ft/min. The maximum rate of 0.70 ft/min was achieved with new teeth.

The average cut rate for the SW45 and SW60 using the Caterpillar 375-7681 and Kennametal RP15 in the limestone aggregate PCC was 0.75 ft/min. The saw rates ranged from 0.40 to 1.08 ft/min. The maximum rate of 1.08 ft/min was achieved with new teeth, while the minimum rate of 0.40 ft/min was measured using teeth that had cut 70 ft of PCC (equivalent to approximately two small craters).

The Caterpillar SW60 with the Caterpillar 375-7681 and the Kennametal RP15 teeth was much slower in the 24-in.-thick limestone aggregate PCC with an average saw-cutting rate of 0.57 ft/min, ranging from 0.43 to 0.84 ft/min. The saw-cutting rates dropped approximately 5 percent every 12 ft in the 24-in-thick PCC. The average saw-cutting rates of the Caterpillar SW45 and SW60 wheel saws with either type of cutting bit did not meet the goal of 1 ft/min in either PCC type.

The maximum advertised cut depth for the Caterpillar SW45 wheel saw is 18 in.; however, the typical maximum cut depth achieved during this evaluation was 16.5 in. The same type result occurred with the SW60 wheel saw; the maximum advertised cut depth the for the Caterpillar SW60 wheel saw is 24 in.; however, the typical maximum cut depth achieved during this evaluation was 22.5 in. This was likely due to substantial concrete debris buildup around the saw or the operator not keeping the saw completely horizontal and flush with the PCC.

The Vermeer CC1531 saw’s plunge time was noticeably faster than any other saws’ plunge time, even in the chert aggregate PCC. The CC1531 began progressing forward after an average of about a 1-min plunge through the depth of the 18-in.-thick PCC. The Vermeer RW1236W took an average of 2 and 4 min to plunge through the 18-in.-thick limestone aggregate PCC and chert aggregate PCC, respectively. It took approximately 6 min for the Vermeer RW1236W to plunge through the 24-in.-thick limestone aggregate PCC, while it took the Vermeer CC1531 approximately 2 min. Typical plunge times for the Ditch Witch and Caterpillar saws in the 18- and 24-in.-thick PCC varied from 6 to 9 min and 4 to 8 min for the chert and limestone aggregate, respectively.

The goal stated in the TTPs for repositioning to begin a cut is 1 min. The average reposition time for the Caterpillar saws was just under 1 min. This data is consistent with previous reposition measurements in past evaluations (Edwards et al. 2015). The Vermeer saws are larger machines, so their reposition times were approximately 20 to 50 sec longer than the Caterpillar's time. The reposition time for the Ditch Witch H1140 saw was not measured.

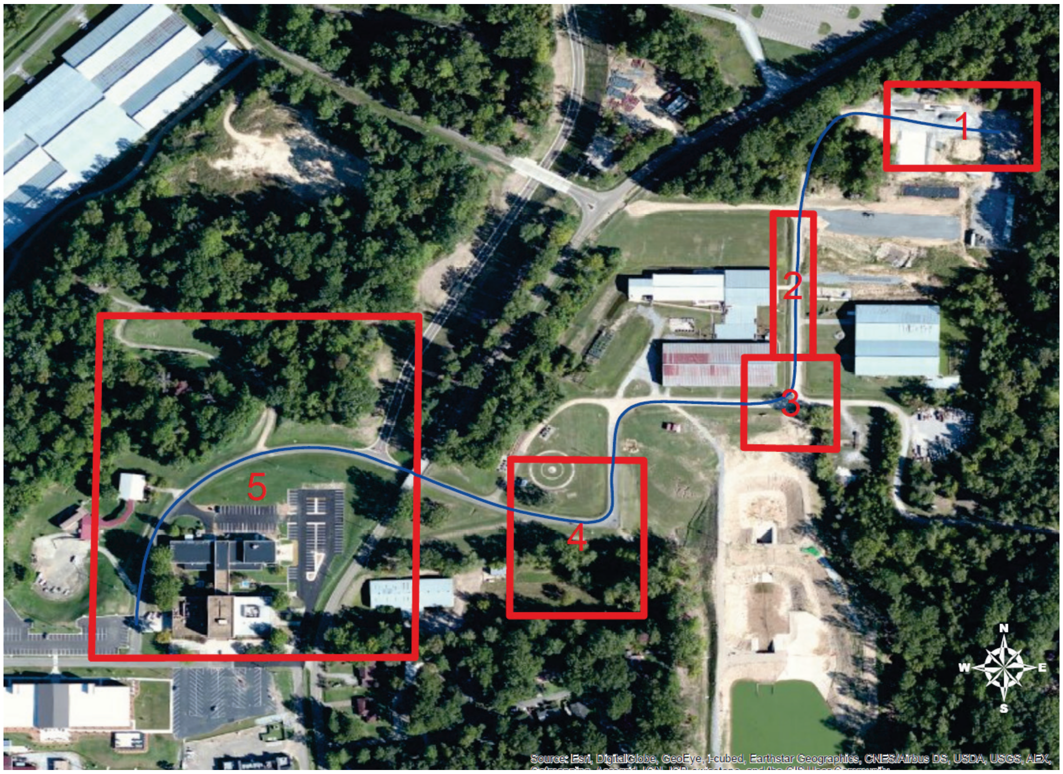
4.2.2 Obstacle course

The Caterpillar SW60 attached to the Caterpillar 279C CTL, the Vermeer RW1236W attached to the Vermeer RTX1250, and the Vermeer CC1531 attached to the Vermeer CC155 were evaluated using an obstacle course shown in Figure 27 and a 0.65-mile distance course shown in Figure 28 (outlined in blue). The obstacle course was designed to evaluate each saw's maneuverability and speed around small craters and in reverse. The distance course was designed to evaluate each saw's speed around curves, on straight and flat surfaces, and over small elevation changes.

The prime mover of each saw was installed with a GoPro Hero3 camera, handheld Trimble GeoExplorer 6000 Series Global Positioning System (GPS), and a 3-D Spectrum Sensors and Controls accelerometer connected to a Campbell Scientific data logger (Figure 29). The GPS measured location and elevation of the machines, while the accelerometer measured acceleration and vibration. The video footage was synced with the GPS route. Figure 30 shows the Vermeer RTX1250 with the RW1236W saw traveling through the obstacle course.

Figure 27. Obstacle course.

Figure 28. Distance course (0.65-mile) marked with areas of interest.



Source: Esri, DigitalGlobe, GeoEye, i-cubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX,

Figure 29. Checking electronics installed on saw before obstacle course.

Figure 30. Completing obstacle course.

The results of the obstacle course are presented in Table 12. The results show that although the Vermeer CC155 with the CC1531 saw had the fastest speed, it did not complete the course in the fastest time. The Caterpillar 279C CTL with the SW60 saw finished approximately 43 sec faster than the Vermeer CC155 and 86 sec (1.43 min) faster than the Vermeer RTX1250. The Vermeer saws were slower because they had to stop and reverse to get around some of the figure eight obstacles, since the machines were larger than the Caterpillar 279C CTL with the SW60 saw. The Vermeer machines and saws, particularly the Vermeer RTX1250 tractor with the RW1236W saw, have a larger turning radius than the Caterpillar CTL and wheel saws. The maneuverability of the Vermeer saws around small craters is not as great as the maneuverability of the Caterpillar saws.

Table 12. Obstacle course results.

Prime Mover	Saw	Speed (mph)			Time (min)
		Max	Min	Avg	
Vermeer RTX1250	Vermeer RW1236W	5.34	4.99	5.11	3.18
Vermeer CC155	Vermeer CC1531	7.27	6.92	7.11	2.47
Caterpillar 279C	Caterpillar SW60	6.45	5.79	6.24	1.75

Table 13 presents the average peak vibration, average time, and average speed results of the 0.65-mile trek around curves and up and down small elevation changes on gravel and asphalt pavement. The longer setup of the Vermeer RTX1250 with the RW1236W saw had less vibration in all directions than the more compact Vermeer CC155 with the CC1531 saw. In general, the Caterpillar 279C CTL with the SW60 wheel saw had four to five times more vibration than the Vermeer RTX1250 with the RW1236Wsaw and about twice as much vibration as the Vermeer CC155 with the CC1531 saw.

Table 13. Distance course (0.65-mile) results.

Prime Mover	Saw	Average Peak Vibration (g)			Average Time (min)	Average Speed (mph)
		side to side	front to back	up and down		
Vermeer RTX1250	Vermeer RW1236W	0.73	0.67	1.50	5.18	7.58
Vermeer CC155	Vermeer CC1531	1.50	1.55	3.40	4.06	9.66
Caterpillar 279C	Caterpillar SW60	2.67	2.53	7.20	4.71	8.32

According to Table 13, no direct relationship exists between the speed or timing results and the vibration of the equipment. At almost 10 mph, the Vermeer CC155 completed the route in the fastest time, followed by the Caterpillar 279C then the Vermeer RTX1250. All prime movers were operated at maximum speed during the entire 0.65-mile course.

Figure 28 shows the distance course outlined in blue beginning with area of interest 1 (AOI1) and ending with AOI5. AOI1 was the start of the test and included approximately 270 ft of flat terrain consisting of PCC and gravel. AOI2 and AOI3 consisted of approximately 400 and 200 ft, respectively, of flat gravel terrain, with the exception that AOI3 had a 90-deg curve. AOI4, approximately 390 ft long, included a 90-deg turn on flat asphalt pavement. The end of the test, labeled AOI5, was on approximately 1,000 ft of asphalt pavement with an uphill grade of 1 percent.

Table 14 presents the average speed and timing results of the 0.65-mile distance course at each specified AOI. The results show that one machine was not particularly faster on certain surfaces. The 90-deg turns also had no major effects on the speeds of the machines. All technologies were the slowest at AOI1, due to the machines gaining their speed at the beginning of the evaluation. AOI5 was the next slowest speed for all machines, although the Vermeer RTX1250 had essentially the same speed in AOI3. AOI5 included the 1 percent climb to the finish line.

Table 14. Distance course results at various areas of interest (AOI).

	Vermeer RTX1250			Vermeer CC155			Caterpillar 279C		
Area of Interest	Distance (ft)	Avg. Speed (mph)	Avg. Time (sec)	Distance (ft)	Avg. Speed (mph)	Avg. Time (sec)	Distance (ft)	Avg. Speed (mph)	Avg. Time (sec)
AOI1	275	7.22	26	270	9.22	20	264	7.83	23
AOI2	400	7.91	35	389	9.91	27	399	8.41	32
AOI3	207	7.43	19	215	10.18	15	220	8.18	18
AOI4	386	7.50	35	397	9.94	28	390	8.23	32
AOI5	1,006	7.46	92	1,007	9.60	72	1,005	8.10	85

4.2.3 Overcuts

Controlling the overcuts generated when saw cutting around crater repairs is necessary for decreasing saw cutting and excavation times and minimizing additional damage to the parent slab. For this project, overcut data were collected for the Caterpillar and Vermeer saws. No overcut data were collected for the Ditch Witch H1140 saw due to its late addition to the scope and time constraints. The methods used for determining and measuring the overcuts for the Caterpillar and Vermeer saws at the beginning and end of a cut were aimed to result in overcuts ranging from 4 to 8 in. long.

The saw target system described in Section 3.1.3 was used for collecting overcut data with the Caterpillar wheel saws in the 18- and 24-in.-thick PCC. Figure 31 shows the saw spotter lining up the SW45 saw before beginning a cut.

Figure 31. Spotter lining up Caterpillar SW45 saw to obtain 4- to 8-in-long overcut.

Table 15 presents the results of the overcut data collected with the Caterpillar SW45 wheel saw in the 18-in.-thick PCC. Scatter is seen in the beginning overcut data (ruler placement on the saw), likely due to the variability in the length the saw moves backwards. When the Caterpillar SW45 and SW60 wheel saws begin cutting, the saws move backwards as they plunge through the PCC; lining up the saws can be deceiving for the spotter.

Table 15. Overcut data for Caterpillar SW45 in 18-in.-thick PCC.

	Ruler Position on Saw				Target Position	
SW45	10 in.	12 in.	14 in.	16 in.	17 in.	18 in.
Max (in.)	8.3	10.0	4.8	6.5	6.8	8.0
Min (in.)	5.8	3.5	0.0	4.0	5.3	5.0
Avg (in.)	6.8	6.5	2.9	4.8	6.0	6.7
St Dev (in.)	1.2	1.5	2.2	1.1	0.7	0.8

Edwards et al. (2015) recommends placing the arrow above the 12-in. mark on the ruler adhered to the SW45 saw (Figure 16) and placing the target 18 in. away from the end of the marked corner (Figure 12) to achieve overcuts ranging from 4 to 8 in. Data collected during this evaluation show that the ruler should be placed at the 10- or 12-in. mark on the saw and the target should be placed 17 to 18 in. away from the end of the marked corner (Table 15). For consistency and simplicity, it is recommended to position the arrow at the 12-in. mark on the ruler adhered to the saw and place the target 18 in. from the end of the marked corner as recommended by Edwards et al. (2015). This will produce overcuts in the 4- to 8-in.-long range.

The overcuts made with the Caterpillar SW60 wheel saw were measured with the same saw target system as the SW45 saw. The overcut results are presented in Table 16. The results from the arrow positions evaluated (12, 14, and 16 in.) did not give an average beginning overcut in the 4- to 8-in. range. However, linear extrapolation shows that the arrow should be placed above the 18- to 22-in. mark to give a beginning overcut in the 4- to 8-in.-long range. It is recommended to position the arrow above the 20-in. mark, which should give an approximate 6-in.-long overcut. The human error associated with the spotter lining up the saw and the variability with the saw moving backwards as it plunges into the PCC should be alleviated ± 2 in. when the SW60 saw is lined up with the conservative 20-in. mark on the ruler. Also, placing the target approximately 18 in. away from the end of the marked corner will result in an approximate 6-in.-long overcut, just as it does when using the Caterpillar SW45 wheel saw.

Table 16. Overcut data for Caterpillar SW60 in 18-in.-thick PCC

	Ruler Position on Saw			Target Position
SW60	12 in.	14 in.	16 in.	18 in.
Max (in.)	15.0	14.3	9.8	7.0
Min (in.)	8.5	8.0	7.5	6.0
Avg (in.)	11.5	10.9	8.6	6.5
St Dev (in.)	2.68	2.06	1.13	0.46

Table 17 presents the overcut results of using the saw target system with the Caterpillar SW60 in 24-in.-thick PCC. The beginning overcut data are scattered and include a fair amount of error (coefficient of determination or, R^2, is 0.56). However, linear extrapolation of the data in Table 17 shows that the arrow should be placed at the 18-in. mark on the ruler to achieve a 6-in.-long overcut. Additional data are needed to obtain a more precise linear regression.

Table 17. Overcut data for Caterpillar SW60 in 24-in.-thick PCC.

	Ruler Position on Saw			Target Position
SW60	12 in.	14 in.	15 in.	18 in.
Max (in.)	14.5	11.0	12.3	10.5
Min (in.)	14.3	9.8	8.5	6.0
Avg (in.)	14.4	10.4	10.0	7.9
St Dev (in.)	0.18	0.6	1.8	1.5

The saw target for the Caterpillar SW60 saw on the 24-in.-thick PCC was evaluated only at a distance of 18 in. away from the end of the marked corner (Table 17). This resulted in an average overcut of approximately 8 in, which is consistent with the results obtained in Edwards et al. (2015). Additional data are needed to determine at what distance away from the end of a marked corner the target should be positioned to achieve 4- and 6-in.-long overcuts when cutting in 24-in.-thick PCC with the Caterpillar SW60 wheel saw. The linear regression for the same scenario in Edwards et al. (2015) shows that the target should be situated approximately 16 to 18 in. from the end of a marked corner to achieve overcuts in the 4- to 8-in.-long range.

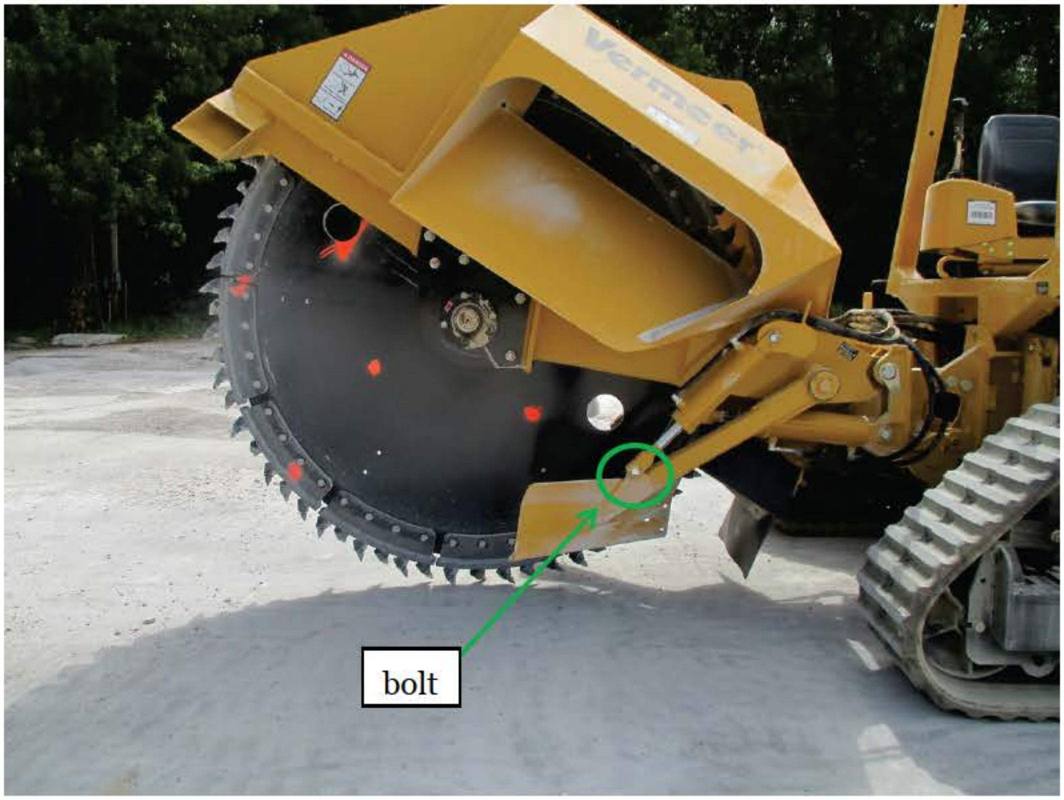
This project was the first instance overcut data were collected for the Vermeer RW1236W and CC1531 saws. Thus, determining where and how to line up the saws and when to stop the saw cutting was initially challenging. Also, the overcut data collected are minimal due to time constraints associated with the rental of the saws. No overcut data were collected in the 24-in.-thick PCC with the Vermeer saws.

Table 18 presents the overcut data collected with the Vermeer RW1236W saw when cutting on the 18-in.-thick PCC. The beginning measurements shown in Table 18 for lining up the saw before a cut were based on the horizontal distance from the outside edge of the outermost cutting tooth. The bolt on the saw was used as a reference for stopping the saw when the cut was completed (Figure 32). The upright saw was stopped once the bolt was lined up with the end of the marked corner of the repair. Positioning the saw target used for the Caterpillar saws approximately 5.75 ft ahead of the grader on the front of the Vermeer RW1236W saw and waiting for the grader to bump the target is equivalent to stopping the saw cutting once the end of the marked corner is aligned with the aforementioned bolt.

Table 18. Overcut data for Vermeer RW1236W in 18-in.-thick PCC.

	Distance from Saw Edge		End Cut
RW1236W	12 in.	14 in.	bolt
Max (in.)	7.0	9.0	10.5
Min (in.)	2.0	6.0	6.5
Avg (in.)	5.1	7.3	7.8
St Dev (in.)	1.7	1.5	1.4

Figure 32. Bolt on Vermeer RW1236W saw used as a reference for stopping a cut.



With the limited data set, Table 18 shows that if the saw is lined up at a distance 12 to 14 in. away from the outside edge of the cutting tooth, the average overcut will be within the recommended 4- to 8-in.-long range. Stopping the cut when the bolt on the saw was lined up with the edge of the marked corner resulted in an average overcut of approximately 8 in. A more conservative overcut would likely result if the saw were stopped when the marked corner was aligned up to 2 in. before the bolt or if the target was placed approximately 5.5 ft ahead of the grader.

The overcut data collected for the Vermeer CC1531 in 18-in.-thick PCC are provided in Table 19. The ruler and arrow combination of the saw target system described in Section 3.1.3 was used on this Vermeer saw because two appropriate locations were available to adhere rulers to the saw (Figure 33). The rulers on the Vermeer CC155 aided in lining up the saw at the beginning of a cut (Figure 34) and stopping the saw at the end of a cut (Figure 35).

Table 19. Overcut data for Vermeer CC1531 saw in 18-in.-thick PCC.

	Arrow Position on Back of Saw			Arrow Position on Middle of Saw			
CC1531	10 in.	12 in.	14 in.	20.5 in.	21 in.	16 in.	14 in.
Max (in.)	5.5	5.3	5.8	9.5	1.0	4.5	10.5
Min (in.)	0.0	2.5	4.0	5.5	-1.0	3.0	5.0
Avg (in.)	2.9	4.1	4.9	6.6	0.0	3.7	7.0
St Dev (in.)	2.3	1.3	1.2	2.0	1.4	0.8	3.0

Figure 33. Rulers on the Vermeer CC155 used to control overcuts.

Figure 34. Ruler on back of Vermeer CC155 saw used to aid in lining up the saw.

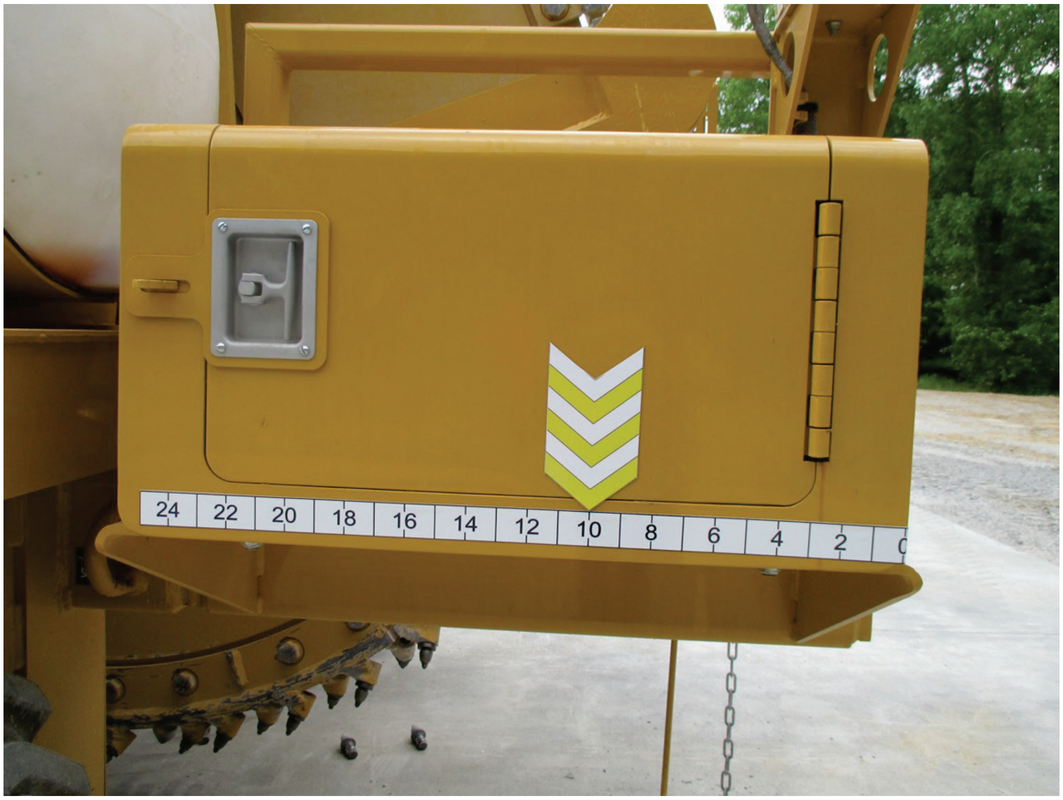


Figure 35. Ruler adhered to middle of Vermeer CC155 to aid in stopping the cut.

Linear extrapolation of the beginning overcut data presented in Table 19 resulted in an R^2 of 0.99. The results show that the arrow above the ruler on the end of the saw should be placed in the 12- to 20-in. range to result in 4- to 8-in.-long overcuts. It is recommended, however, to position the arrow above the 16-in. mark on the ruler located at the back of the saw.

The results of the overcut data collected for the end of the cut revealed a poor linear fit with an R^2 of 0.25. This is likely due to the spotter's perception for stopping the saw cutting when standing a reasonable distance away from the saw. Additional data are needed to determine the arrow position on the middle of the saw to achieve the recommended overcuts.

4.2.4 Teeth durability

The length of the evaluated wheel saw teeth were measured with calipers before cutting began and after various cut lengths throughout the testing (Figure 36). Measuring the teeth lengths after various cuts gave an indication of the durability of each type of tooth and the saw-cutting distance that could be completed before the teeth were completely worn. The same set of 10 marked teeth were measured each time data were collected, and the average wear of those 10 teeth was recorded.

Figure 36. Measuring teeth wear using calipers.

Figure 37 presents the Caterpillar 375-7681 teeth wear on the Caterpillar SW45 and SW60 wheel saws. The Caterpillar SW45 wheel saw performed slightly better in the 18-in.-thick chert aggregate PCC than the Caterpillar SW60 wheel saw when equipped with the Caterpillar 375-7681 teeth. On two occasions, the Caterpillar SW60 sustained an average of 50 percent wear after cutting only 24 ft. According to Edwards et al. (2015), teeth should generally be replaced once the teeth reach an average length of approximately 40 percent of their original length. The Caterpillar SW45 managed to cut approximately 38 ft in the chert aggregate PCC before the Caterpillar 375-7681 teeth reached an average of 40 percent wear.

Figure 37. CAT 375-7681 cutting-bit length versus saw-cut length.

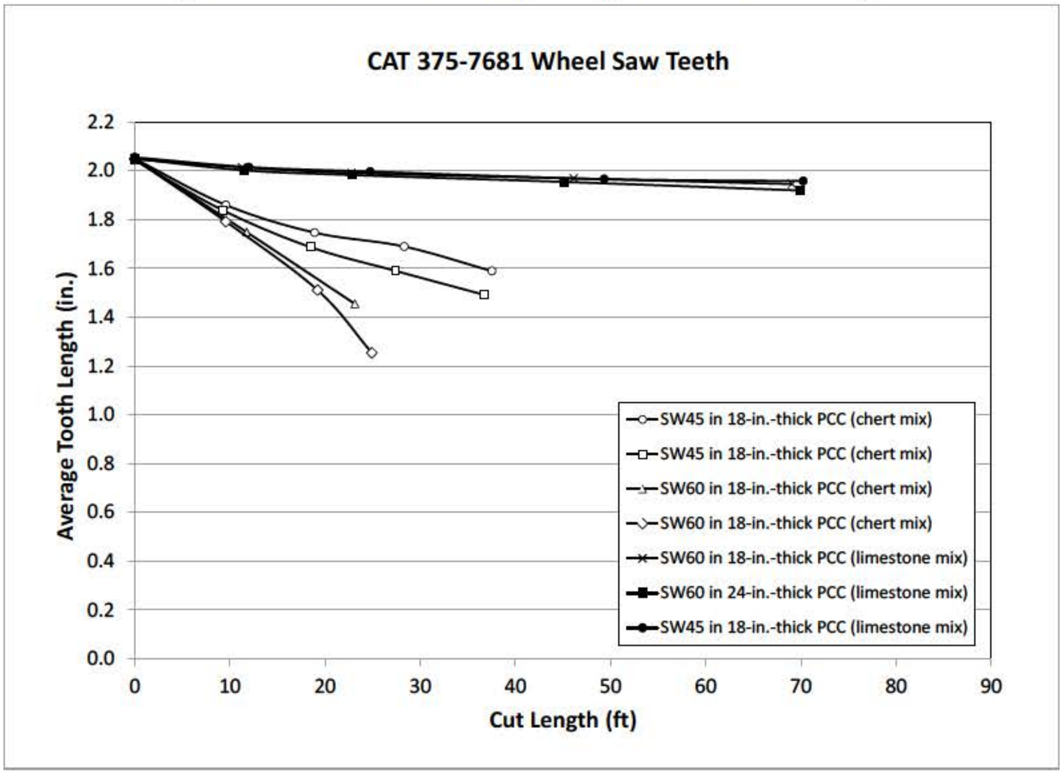


Figure 37 shows a slow rate of decline for the Caterpillar 375-7681 teeth on the Caterpillar SW45 and SW60 wheel saws in the 18- and 24-in.-thick limestone aggregate PCC. The teeth showed 5 percent wear after cutting approximately 70 ft with both saws. Through linear extrapolation, the Caterpillar saws should be able to cut approximately 560 ft of 18- and 24-in.-thick limestone aggregate PCC with the Caterpillar 375-7681 teeth before reaching 40 percent wear on the teeth.

The Caterpillar SW45 saw with the Kennametal RP15 teeth did not hold up well in the chert aggregate PCC (Figure 38). After cutting 35 ft, the teeth had 53 percent wear. A similar situation occurred with the Caterpillar SW60 wheel saw using the Kennametal RP15 teeth. After cutting 39 ft in the chert aggregate PCC, the testing was stopped due to dull teeth. The average wear on the 10 teeth being monitored was approximately 33 percent. The teeth wore differently depending on their position; the majority of the teeth had at least 40 percent wear. Figures 39 and 40 show the wear variation of the Kennametal RP15 teeth in the chert aggregate PCC after 39 ft of cutting.

The Kennametal RP15 teeth were significantly more durable in the limestone aggregate PCC. After cutting 161 ft with the Caterpillar SW45, the teeth wore approximately 6 percent. Extrapolation shows that the Caterpillar saws should be able to cut approximately 1,070 ft with the Kennametal RP15 teeth in the 18- and 24-in.-thick limestone aggregate PCC. The Kennametal RP15 teeth are almost twice as durable as the Caterpillar 375-7681 teeth when used on the Caterpillar SW45 and SW60 wheel saws in the limestone aggregate PCC.

Figure 38. Kennametal RP15 cutting-bit length versus saw-cut length.

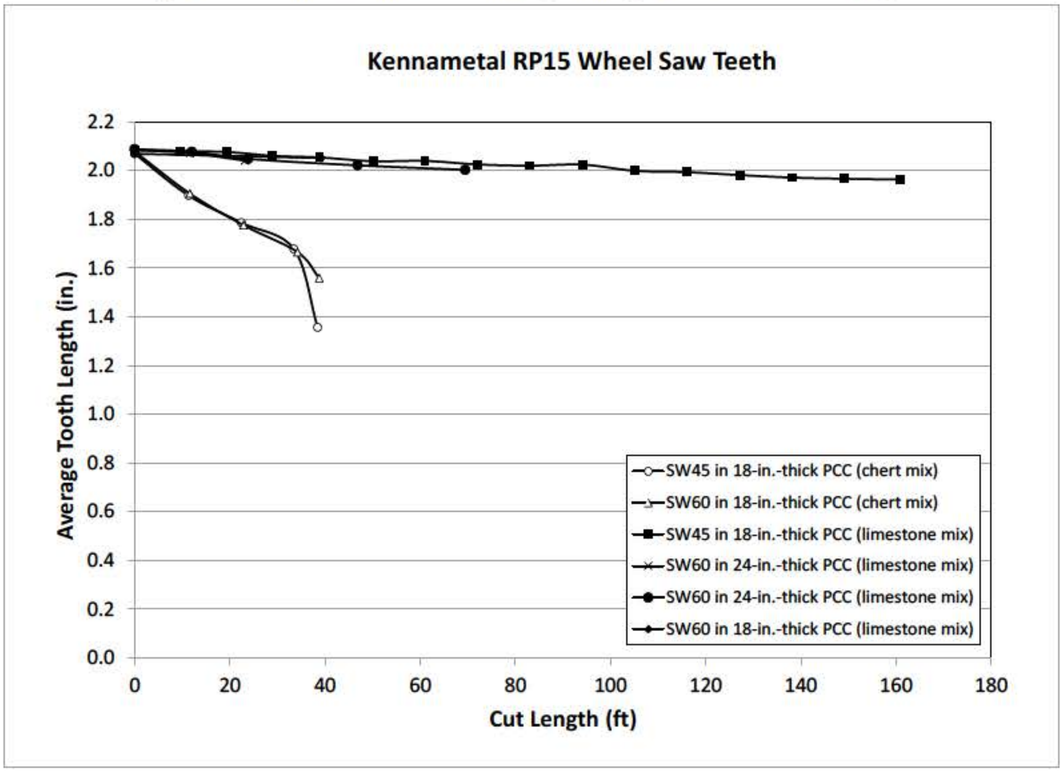


Figure 39. Worn Kennametal RP15 tooth on CAT SW45 after cutting in chert PCC.

Figure 40. Short Kennametal RP15 tooth on CAT SW45 after cutting in chert PCC.

Figure 41 shows that the Kennametal SM04 teeth used on the Vermeer saws were more durable in the limestone aggregate PCC when compared to the chert aggregate PCC; however, their differences were much smaller than the other types of teeth tested. The Kennametal SM04 teeth were more durable on the CC1531 saw than on the RW1236W saw. After extrapolating, the Kennametal SM04 teeth on the Vermeer RW1236W should be able to cut 1,270 ft in the limestone aggregate PCC and only 208 ft in the chert aggregate PCC before obtaining 40 percent wear. Extrapolating also shows the Kennametal SM04 teeth on the Vermeer CC1531 should be able to cut approximately 1,970 ft in the limestone aggregate PCC and 1,040 ft in the chert aggregate PCC before obtaining 40 percent wear. Figure 42 shows the Kennametal SM04 teeth after cutting approximately 100 ft in the chert aggregate PCC. The Kennametal SM04 teeth wore evenly on both Vermeer saws.

Figure 41 also shows that the 10 Kennametal SM04 teeth being monitored on the Ditch Witch H1140 saw were 45 percent worn after 8 ft of cutting in the chert aggregate PCC. All teeth were completely worn, some of the carbide tips had broken away from the steel, and some of the shoes holding the teeth were damaged (Figure 43). It is likely the average wear of the all teeth on the saw was greater than 45 percent.

Figure 41. Kennametal SM04 cutting-bit length versus saw-cut length.

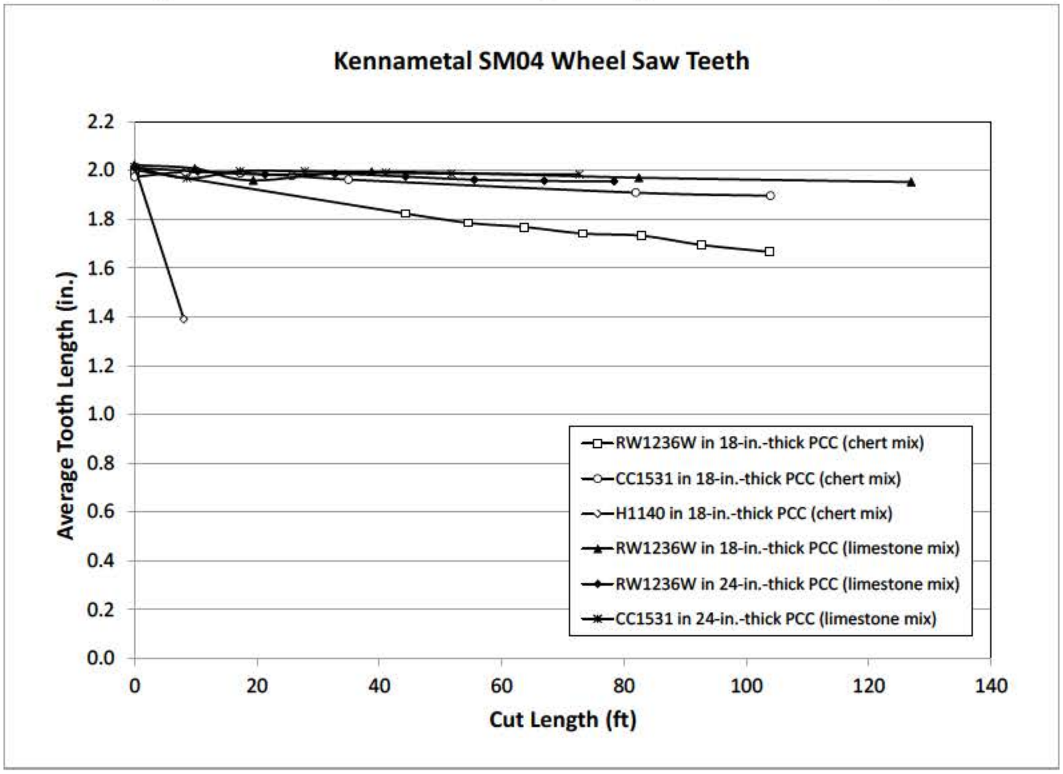


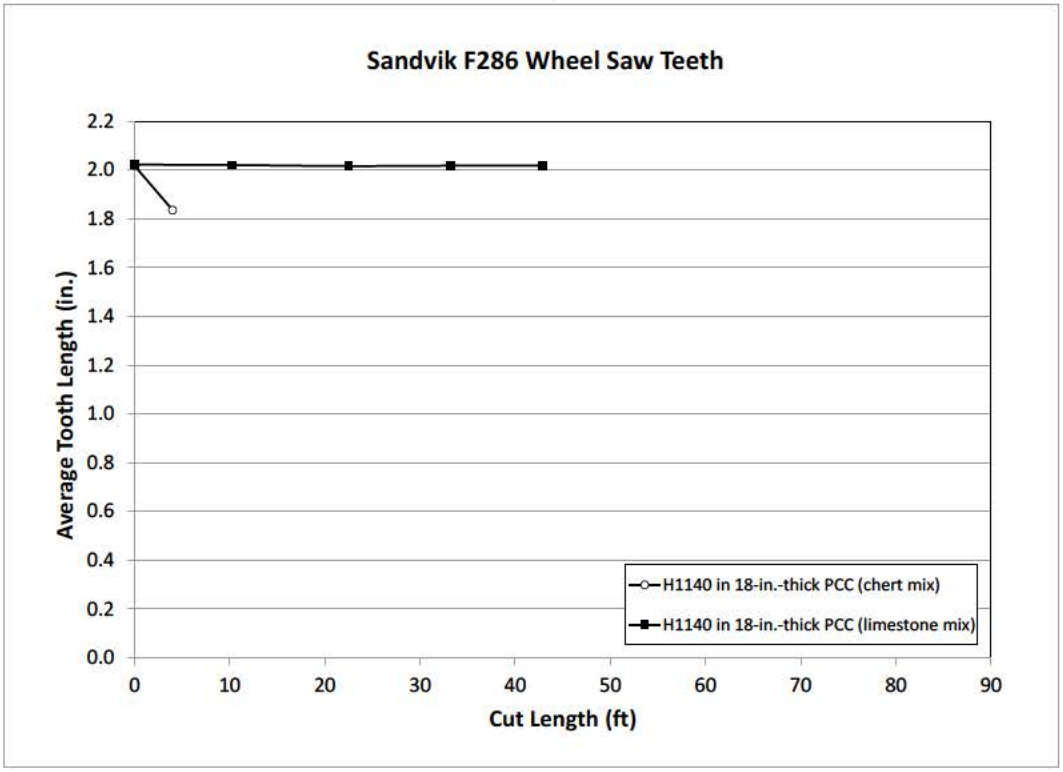
Figure 42. Kennametal SM04 teeth after cutting with Vermeer CC1531 in chert PCC.

Figure 43. Kennametal SM04 teeth after cutting in chert PCC with Ditch Witch H1140 saw.

Figure 44 shows that the Sandvik F286 teeth on the Ditch Witch H1140 saw were not durable in the chert aggregate PCC. The test was stopped prematurely after cutting 4 ft and obtaining only 10 percent wear when measuring the monitored 10 teeth. The teeth did not wear evenly. The carbide tips on some teeth were broken away from the steel and others were badly worn. However, some teeth were still in good condition. It is assumed that the average wear of all of the Sandvik F286 teeth on the Ditch Witch H1140 wheel saw was at least 40 percent.

The Sandvik F286 teeth on the Ditch Witch H1140 saw were more durable in the limestone aggregate PCC; however, the difference in durability is not as great as it appears in Figure 44. The 10 teeth being monitored for wear showed 0 percent wear after cutting 43 ft in the limestone aggregate PCC. Conversely, several teeth that were not being quantitatively monitored were much shorter than the monitored teeth. Again, the teeth wear was not consistent, so it was difficult to estimate the average wear on the entire set of teeth. Extrapolating to determine how many feet of linear cutting the Ditch Witch H1140 saw with the Sandvik F286 teeth can achieve in the limestone aggregate PCC is not possible due to the limited data measured from this evaluation.

Figure 44. Sandvik F286 cutting-bit length versus cut length.



The Sandvik F203 teeth measured 3 percent wear after cutting 39 ft with the Ditch Witch H1140 saw in the limestone aggregate PCC, as shown in Figure 45. However, the test was stopped prematurely due to some teeth being completely flat and worn; other teeth showed no discernible wear. Figure 46 shows the Sandvik F203 teeth after a single cut in the limestone aggregate PCC. Some teeth are worn completely on one side, and some are not.

The Sandvik F203 teeth on the Ditch Witch H1140 saw were not durable enough to cut in the 18-in.-thick chert aggregate PCC. After cutting just over 10 ft, the 10 teeth being monitored averaged 19 percent wear. The test was stopped prematurely due to the majority of the teeth being completely worn, despite measuring 19 percent wear. Some teeth were broken, and some were in fair condition. Figure 47 shows the Sandvik F203 teeth after cutting in the chert aggregate PCC. Both cuts were made while misting water on the saw. Extrapolation was not conducted.

Figure 45. Sandvik F203 cutting-bit length versus cut length.

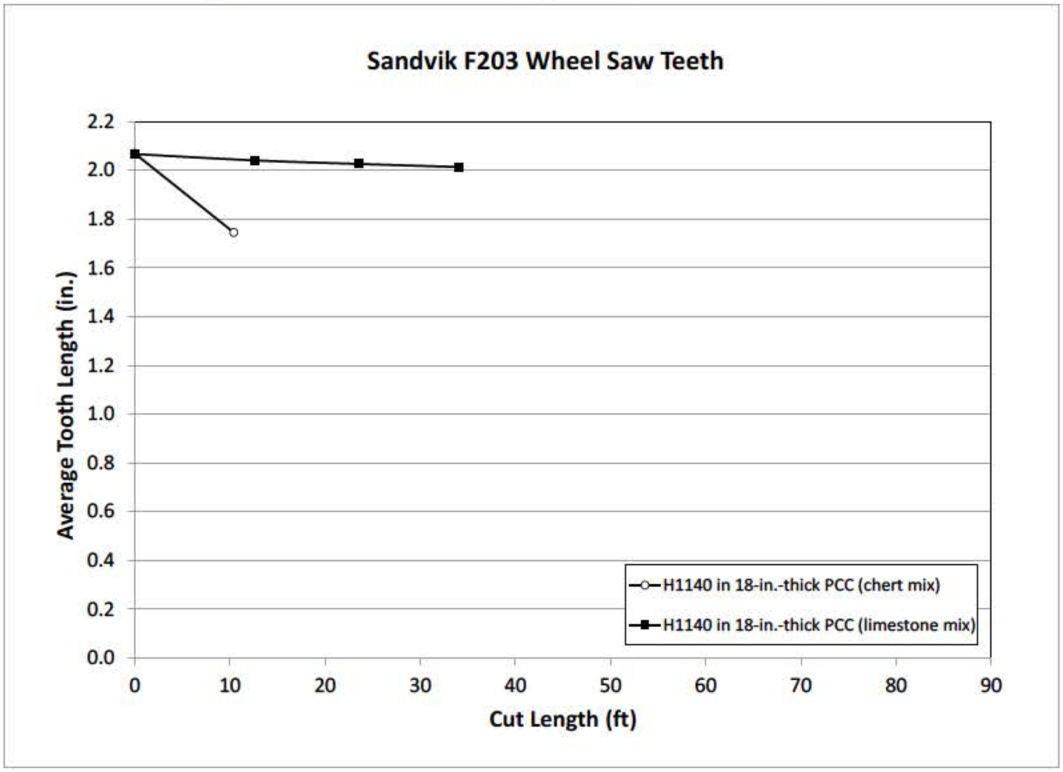


Figure 46. Sandvik F203 teeth after a wet cut through limestone aggregate PCC.

Figure 47. Sandvik F203 teeth after cutting through chert aggregate PCC.

Water was misted on the Sandvik teeth during some of the tests, as shown in Figure 48, in an effort to keep the teeth rotating freely and prevent them from overheating and breaking off. According to the Sandvik representative, the carbide tips will break away from the steel when they are above 600°F. The water used on the Ditch Witch saw did keep the dust settled more, but it did not help the teeth rotate freely or prevent the carbide tips from breaking off from the steel shanks. No teeth were broken using the Caterpillar or Vermeer saws, even without the use of water.

All teeth and saw combinations spalled the cut edges of the PCC when cutting. Spalling is defined as the breakdown or raveling of slab edges and can lead to an elevated rate of PCC deterioration. Spalled edges can negatively impact a rapid-setting concrete repair cap by creating foreign object debris (FOD) around the repair edges during trafficking. Figure 49 through Figure 52 show examples of the chert and limestone aggregate PCC after sawing with the Caterpillar and Vermeer wheel saws with Kennametal cutting bits. Every saw and tooth combination spalled the PCC during the testing.

Figure 48. Misting water on Ditch Witch H1140 saw during saw cutting.

Figure 49. Spalling of chert PCC from Kennametal RP15 teeth on CAT SW60.

Figure 50. Spalling of limestone PCC from Kennametal RP15 teeth on CAT SW45.

Figure 51. Spalling of limestone PCC with Kenn SM04 teeth on Vermeer RTX1250.

Figure 52. Spalling of chert PCC with Kenn SM04 teeth on Vermeer CC1531.

4.3 Summary

Currently, for a typical small crater repair scenario, two wheel saws are required to saw cut around the upheaval area of 18 craters approximately 8.5 by 8.5 ft (Air Force Civil Engineer Center, in preparation). Each wheel saw is needed to cut a total of approximately 340 ft. The goal for saw cutting is 1 ft/min with 1 min for saw repositioning to begin a new linear cut (Air Force Civil Engineer Center, in preparation). Table 20 presents a summary of the average saw-cutting rates and approximate extrapolated cutting lengths for teeth at 40 percent wear.

As mentioned previously, all teeth evaluated on the Ditch Witch H1140 saw wore prematurely and unevenly; therefore, extrapolation was not possible to determine how many linear feet the saw could cut before the teeth experienced 40 percent wear. Based on the limited data presented in the previous section, it is presumed any teeth used on the Ditch Witch H1140 wheel saw would need to be replaced multiple times before completing the required 340 ft of linear saw cutting.

Table 20. Saw-cutting rates and teeth wear in 18-in.-thick PCC.

Wheel Saw	Cutting Teeth	Average Saw-Cutting Rate (ft/min)		Estimated Saw-Cutting Distance at 40% Teeth Wear (ft)	
		Limestone PCC	Chert PCC	Limestone PCC	Chert PCC
Caterpillar SW45	CAT 375-7681	0.62	0.50	560	38
	Kennametal RP15	0.83	0.41	1,070	26
Caterpillar SW60	CAT 375-7681	0.72	0.47	560	19
	Kennametal RP15	0.84	0.46	1,070	-----[a]
Vermeer RW1236W	Kennametal SM04	3.21	1.78	1,270	208
Vermeer CC1531	Kennametal SM04	5.18	4.51	1,970	1,040
Ditch Witch H1140	Sandvik F286	1.94	1.71	-----[a]	-----[a]
	Sandvik F203	1.46	0.79	-----[a]	-----[a]
	Kennametal SM04	-----[b]	0.70	-----[a]	-----[a]

[a] Extrapolation not possible due to uneven teeth wear

[b] Teeth not evaluated in limestone PCC mix

Table 20 shows that all combinations of Caterpillar and Vermeer saws and Caterpillar and Kennametal teeth assessed would be able to complete the required 340 ft of linear saw cutting in 18-in.-thick limestone-mixed PCC for small crater repairs without having to stop and replace worn teeth. The Kennametal RP15 teeth on the Caterpillar SW45 and SW60 wheel saws are faster and more durable than the Caterpillar 375-7681 teeth in the limestone-mixed PCC. The opposite was shown to be true in the chert-mixed PCC; although the rates and wear were similar, the CAT 375-7681 teeth were faster and more durable in the chert-mixed PCC. Regardless, the saw cutting of the 18 small crater repairs in the 18-in.-thick chert-mixed PCC would result in stopping and replacing the worn teeth 9 (SW45 saw) to 18 (SW60 saw) times. It is unlikely that the Vermeer CC1531 saw would require teeth changing prior to completing the required 340 ft of linear cutting in the 18-in.-thick chert-mixed PCC. However, the Kennametal SM04 teeth on the Vermeer RW1236W would have to be replaced at least once.

With an average rate almost eight times as fast as the Caterpillar SW45 and SW60 wheel saws in the limestone-mixed PCC, one Vermeer CC1531 saw would be able to cut all 18 crater repairs by itself in a quarter of the time and with less teeth wear when compared to the combined work of two Caterpillar wheel saws. Furthermore, the Vermeer RW1236W would be able to cut all 18 crater repairs by itself in less than half the time and with less teeth wear when compared to the combined work of two Caterpillar wheel saws. This also accounts for the additional reposition time (approximately 30 sec) needed for the larger Vermeer saws.

If a thick chert-mixed PCC is encountered, then the teeth on all wheel saws, with the exception of the Vermeer CC1531 saw, will need to be replaced before the saw team completes the cutting around the 18 crater repairs. The teeth can be replaced manually by using a mallet and punch tool or by using an air gun operated off an air compressor. The air gun was used to put the Sandvik teeth on the Ditch Witch saw with a time of approximately 6 min; this time involved one person holding the air gun and one person handing the operator one tooth at a time. It took approximately 15 min for two people to put the Kennametal teeth on the Vermeer RW1236W saw using a mallet and punch tool. The mallet and punch tool are typically used for putting the teeth on the Caterpillar SW45 and SW60 wheel saws. The time to put teeth on these smaller saws using this method is approximately 10 min.

The Caterpillar 279C CTL equipped with the Caterpillar SW45 and SW60 wheel saws and the Vermeer CC155 with the CC1531 wheel saw cut in the forward direction; the saws are in front of the prime movers. The Ditch Witch RT120 Quad tractor equipped with the H1140 saw and the Vermeer RTX1250 machine equipped with the RW1236W wheel saw cut in the reverse direction; the saws are behind the prime movers and are pulled instead of pushed. The Vermeer RTX1250 and Ditch Witch RT120 Quad prime movers and saws are designed for digging ditches and placing cables in the ground. Wheel saws exhibit more power when they have the force of the prime mover behind them. This is likely the reason that the Vermeer CC1531 had better performance than the Vermeer RTX1250.

5 Conclusions and Recommendations

ERDC performed full-scale field evaluations of crater repair equipment and tools to identify methods for increasing efficiency and production rates of sawing small craters for repair purposes. The full-scale test section was constructed using two PCC mixture types, one with chert aggregate and one with limestone aggregate. The hardness of the aggregates in the concrete mix had a large effect on the sawing rates and cutting teeth durability. The following sections present the conclusions and recommendations resulting from the study of the Vermeer, Caterpillar, and Ditch Witch saws and Kennametal, Caterpillar, and Sandvik conical cutting bits.

5.1 Conclusions

- The Caterpillar Sw45 and SW360B wheel saws were not capable of cutting the required depths of 18 and 24 in. deep, respectively. The SW45 and SW60 wheel saws effectively cut to maximum depths of 16.5 and 22.5 in., respectively.
- The Vermeer CC1531 wheel saw on the CC155 machine was the fastest evaluated saw in both the limestone and chert-mixed PCC.
- The Vermeer RW1236W wheel saw on the RTX1250 machine was the second fastest evaluated saw in both the limestone- and chert-mixed PCC.
- The Caterpillar SW45 and SW60 wheel saws were faster with the Kennametal RP15 teeth than when using the Caterpillar 375-7681 teeth in the limestone PCC mix, yet they had similar saw-cutting rates when compared in the chert PCC mix.
- Although their saw-cutting rates were similar, the Kennametal RP15 teeth on the Caterpillar saws were approximately twice as durable as the Caterpillar 375-7681 teeth on the Caterpillar wheel saws.
- The Vermeer RTX1250 saw had the slowest repositioning time, followed by the Vermeer CC1531 and then the Caterpillar SW45 and SW60 wheel saws.
- The Kennametal RP15 teeth were almost twice as durable as the Carterpillar 375-7681 teeth when used on the Caterpillar SW45 and SW60 wheel saws in the limestone aggregate PCC.
- The Kennametal SM04 teeth were more durable on the Vermeer CC1531 saw than on the Vermeer RW1236W saw.

- Only the Sandvik F203 teeth tested on the Ditch Witch were able to successfully complete a cut in the chert.
- The water misted on the Ditch Witch H1140 saw during testing did keep the dust settled more, but it did not help the teeth rotate freely or prevent the carbide tips from breaking off the steel shanks. No teeth were broken on the Caterpillar or Vermeer saws, even without the use of water.
- The Sandvik F286 teeth, which are equivalent to the Kennametal SM04 and Caterpillar RP15, show promise for use on the Vermeer and Ditch Witch equipment in limestone PCC mixtures.
- All teeth and saw combinations spalled the cut edges of the PCC when cutting through the 18- and 24-in.-thick pavement.

5.2 Recommendations

- Based on the work of Edwards et al. (2014), the goal for overcutting should be in the 4- to 8-in.-long range when sawing around upheaval. The Caterpillar SW45 should be lined up at 12 in. on the ruler, and the end target should be placed 18 in. away from the end of the marked line. Due to the perception of the spotter lining up the wheel saw, the actual overcut length will vary but should be in the desired range.
- For best results with the Caterpillar wheel saw attachments, the Kennametal RP15 wheel saw teeth should be used.
- For best results with the Vermeer saws, the Kennametal SM04 wheel saw teeth should be used.
- The saw spotter should watch the saw teeth to determine when they should be replaced. The teeth should be replaced when they have worn approximately 40 percent of the original length. At this point, the carbide tip will have worn off, and the teeth should be replaced to prevent damage to the saw itself.
- It is recommended to evaluate the Sandvik F286 teeth on the Vermeer RW1236W and CC1531 wheel saws.

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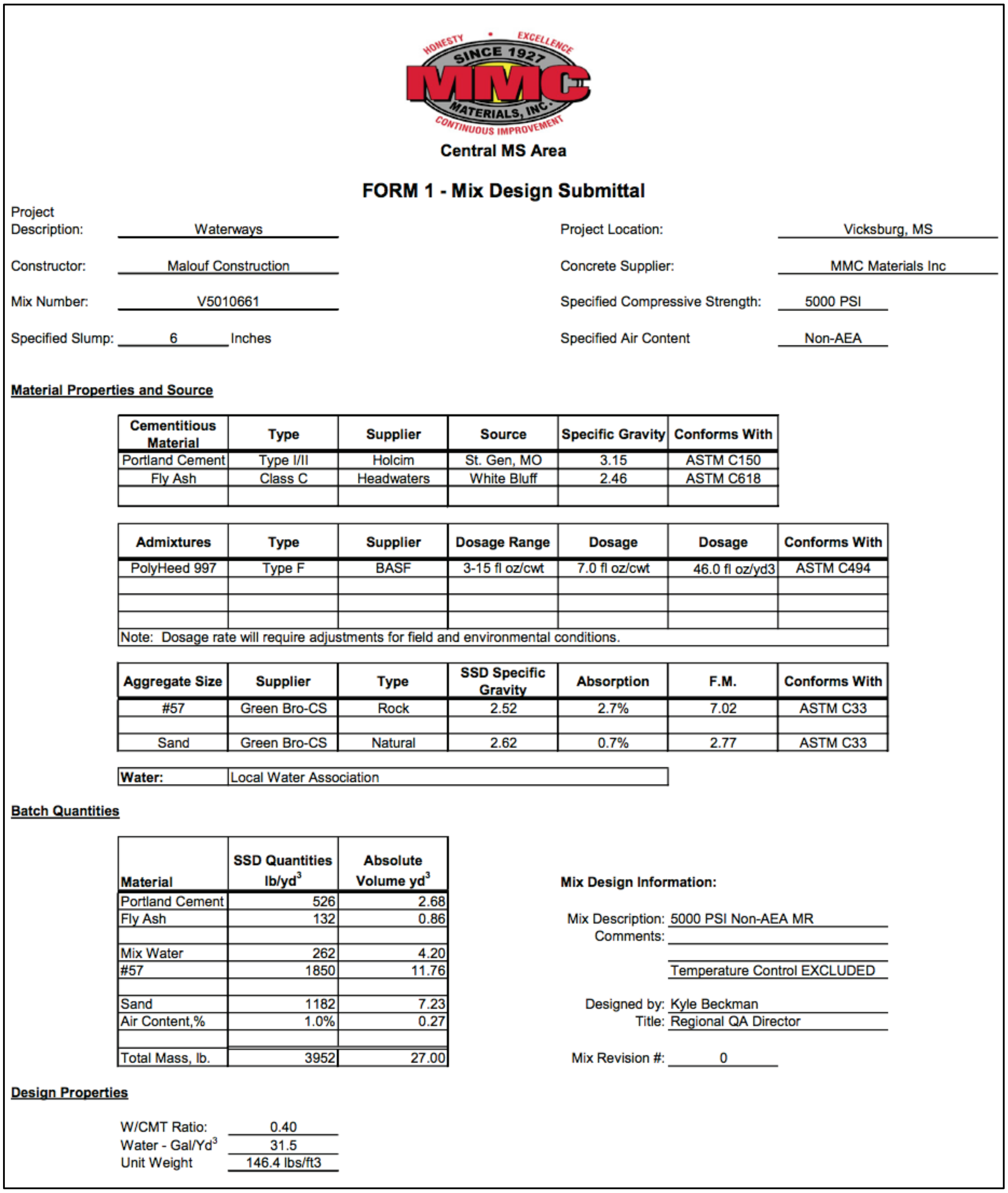
Appendix A: PCC Mix Designs

Figure A1. Chert aggregate PCC mix design.



Central MS Area

FORM 1 - Mix Design Submittal

Project Description: Waterways

Project Location: Vicksburg, MS

Constructor: Malouf Construction

Concrete Supplier: MMC Materials Inc

Mix Number: V5010661

Specified Compressive Strength: 5000 PSI

Specified Slump: 6 Inches

Specified Air Content Non-AEA

Material Properties and Source

Cementitious Material	Type	Supplier	Source	Specific Gravity	Conforms With
Portland Cement	Type I/II	Holcim	St. Gen, MO	3.15	ASTM C150
Fly Ash	Class C	Headwaters	White Bluff	2.46	ASTM C618

Admixtures	Type	Supplier	Dosage Range	Dosage	Dosage	Conforms With
PolyHeed 997	Type F	BASF	3-15 fl oz/cwt	7.0 fl oz/cwt	46.0 fl oz/yd3	ASTM C494
Note: Dosage rate will require adjustments for field and environmental conditions.						

Aggregate Size	Supplier	Type	SSD Specific Gravity	Absorption	F.M.	Conforms With
#57	Green Bro-CS	Rock	2.52	2.7%	7.02	ASTM C33
Sand	Green Bro-CS	Natural	2.62	0.7%	2.77	ASTM C33

Water:	Local Water Association

Batch Quantities

Material	SSD Quantities lb/yd^3	Absolute Volume yd^3
Portland Cement	526	2.68
Fly Ash	132	0.86
Mix Water	262	4.20
#57	1850	11.76
Sand	1182	7.23
Air Content,%	1.0%	0.27
Total Mass, lb.	3952	27.00

Mix Design Information:

Mix Description: 5000 PSI Non-AEA MR

Comments:

Temperature Control EXCLUDED

Designed by: Kyle Beckman

Title: Regional QA Director

Mix Revision #: 0

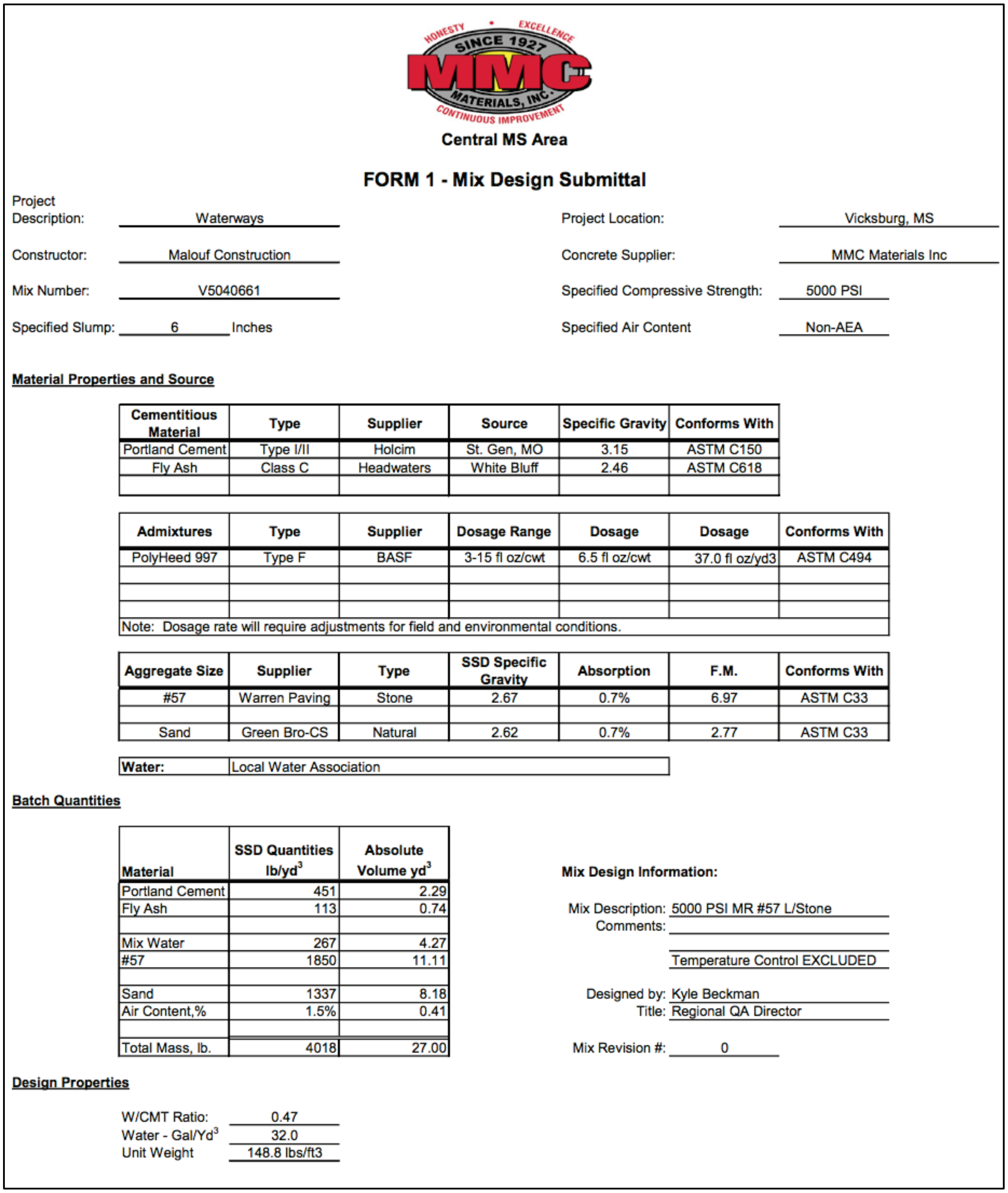
Design Properties

W/CMT Ratio: 0.40

Water - Gal/Yd^3 31.5

Unit Weight 146.4 lbs/ft3

Figure A2. Limestone aggregate PCC mix design.



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Central MS Area

FORM 1 - Mix Design Submittal

Project Description: Waterways
Project Location: Vicksburg, MS
Constructor: Malouf Construction
Concrete Supplier: MMC Materials Inc
Mix Number: V5040661
Specified Compressive Strength: 5000 PSI
Specified Slump: 6 Inches
Specified Air Content Non-AEA

Material Properties and Source

Cementitious Material	Type	Supplier	Source	Specific Gravity	Conforms With
Portland Cement	Type I/II	Holcim	St. Gen, MO	3.15	ASTM C150
Fly Ash	Class C	Headwaters	White Bluff	2.46	ASTM C618

Admixtures	Type	Supplier	Dosage Range	Dosage	Dosage	Conforms With
PolyHeed 997	Type F	BASF	3-15 fl oz/cwt	6.5 fl oz/cwt	37.0 fl oz/yd3	ASTM C494
Note: Dosage rate will require adjustments for field and environmental conditions.						

Aggregate Size	Supplier	Type	SSD Specific Gravity	Absorption	F.M.	Conforms With
#57	Warren Paving	Stone	2.67	0.7%	6.97	ASTM C33
Sand	Green Bro-CS	Natural	2.62	0.7%	2.77	ASTM C33

Water:	Local Water Association

Batch Quantities

Material	SSD Quantities lb/yd^3	Absolute Volume yd^3
Portland Cement	451	2.29
Fly Ash	113	0.74
Mix Water	267	4.27
#57	1850	11.11
Sand	1337	8.18
Air Content,%	1.5%	0.41
Total Mass, lb.	4018	27.00

Mix Design Information:

Mix Description: 5000 PSI MR #57 L/Stone
Comments:
Temperature Control EXCLUDED
Designed by: Kyle Beckman
Title: Regional QA Director
Mix Revision #: 0

Design Properties

W/CMT Ratio: 0.47
Water - Gal/Yd^3 32.0
Unit Weight 148.8 lbs/ft3

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14. ABSTRACT

Research was conducted at the U.S. Army Engineer Research and Development Center in Vicksburg, MS, to evaluate saw-cutting equipment for use by crater repair teams in airfield damage repair (ADR) scenarios. The evaluation included measuring the saw-cutting rates and conical cutting bit wear of commercial saw cutting equipment in both soft and hard PCC mixtures. The investigated equipment included the Vermeer RW1236W and CC1531, Caterpillar SW45 and SW60, and Ditch Witch H1140 wheel saws outfitted with various cutting bits. This report presents the technical evaluation of the various saw technologies and tools for improving the efficiency of sawing around damaged pavement associated with crater repair. Results indicate that the Vermeer saws with the Kennametal SM04 teeth provide the most efficient saw-cutting rates with the least teeth wear, followed by the Caterpillar wheel saws with the Kennametal RP15 teeth. These two saw technologies are recommended to be considered for use by ADR crater repair teams.

15. SUBJECT TERMS

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Saw cutting
ADR
Wheel saw

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