Chapter 5
Concrete Removal and Preparation for Repair

5-1. Introduction

Most repair projects involve removal of distressed or deteriorated concrete. This chapter discusses removal of concrete, preparation of concrete surfaces for further work such as overlays, preparation and replacement of reinforcing steel that has been exposed during concrete removal, and anchorage systems. Regardless of the cost or complexity of the repair method or of the material selected, the care with which deteriorated concrete is removed and with which a concrete surface is prepared will often determine whether a repair project will be successful.

5-2. Concrete Removal

a. Alternatives. Repair techniques requiring no concrete removal should be considered for situations where the deteriorated and damaged concrete does not threaten the integrity of the member or structure. The cost of concrete removal was saved in the rehabilitation of the tops of lock walls at Dashields Locks, U.S. Army Engineer District, Pittsburgh, by placement of an unbonded concrete overlay without removal of the deteriorated concrete. Similarly, the cost of concrete removal was saved by installation of precast concrete panels over deteriorated concrete on the backside of river walls at Lockport Lock in the U.S. Army Engineer District, Rock Island, and Troy Lock in the U.S. Army Engineer District, New York.

b. Environment. An evaluation to assess the impact of concrete removal debris entering a river, stream, or waterway is required before a contract is awarded. The impact varies from project to project and depends to a great extent on the size and environmental condition of the waterway and on the quantity of removal debris entering the waterway. The coarse-aggregate portion of the debris is sometimes a natural river gravel that is being returned to its place of origin and therefore its impact on the waterway is generally considered negligible. When debris fragments are of sufficient size, debris can be placed in open water to construct a fish attractor reef as an means of disposal. Recycling of concrete debris should be considered as an alternative to landfill disposal.

c. Contract work. If work is to be contracted, the information describing the condition and properties of the concrete must be made available at the time of invitation for bids to reduce the potential for claims by the contractor of "differing site conditions." Information provided may include type and range of deterioration, nominal maximum size and type of coarse aggregate, percentage of reinforcing steel, compressive and splitting-tensile strengths of concrete, and other pertinent information. When uncertainties exist regarding the condition of the concrete or the performance of the removal technique(s), an onsite demonstration should be implemented to test production rates and ensure acceptable results before work is begun.

d. General considerations. Several general considerations should be kept in mind in the selection of a concrete removal method:

(1) Usually, a repair or rehabilitation project will involve removal of deteriorated concrete. However, for many maintenance and repair projects, concrete is removed to a fixed depth to ensure that the bulk of deteriorated concrete is removed or to accommodate a specific repair technique. For some projects, this requirement would cause a significant amount of sound concrete to be removed and, thereby, a change in removal method(s), since some methods are more cost effective for sound concrete than others.

(2) Selected concrete removal methods should be safe and economical and should have as little effect as possible on concrete remaining in place. Selection of a proper removal method may have a significant effect on the length of time that a structure must be out of service. Some methods permit a significant portion of the work to be accomplished without removing the structure from service. For example, drilling of boreholes in a lock wall in conjunction with removal of concrete by blasting may be done while the lock is operational.

(3) The same removal method may not be suited for all portions of a given structure. The most appropriate method for each portion of the structure should be selected and specified.

(4) More than one removal method may be required for a particular area. For example, a presplitting method may be used to fracture and weaken the concrete to be removed, while an impacting method is used to complete the removal for the same location.

(5) In some instances, a combination of removal methods may be used to limit damage to concrete that is not being removed. For example, a cutting method may

be used to delineate an area in which an impacting method is to be used as the primary means of removal.

(6) Field tests of various removal methods are very well suited for demonstration projects done during the design phase of a major repair or rehabilitation project.

(7) The cost of removal and repair should be compared to the cost of total demolition and replacement of the member or structure if the damage is extensive.

(8) Care should be taken to avoid embedded items such as electrical conduits and gate anchorage's. Dimensions and locations of embedded items documented in the as-built drawings should not be taken for granted.

e. Classification of concrete removal methods. Removal methods may be categorized by the way in which the process acts on the concrete. These categories are blasting, crushing, cutting, impacting, milling, and presplitting. Table 5-1 provides a general description of these categories and lists the specific removal methods within each category. Table 5-2 provides a summary of information on each method. These methods are discussed in detail in the following. See Campbell (1982) for additional information.

f. Blasting methods. Blasting methods employ rapidly expanding gas confined within a series of boreholes to produce controlled fracture and removal of concrete (Figure-5-1). Explosive blasting, the only blasting method commercially available in the United States, is applicable for concrete removal from mass concrete structures where 250 mm (10 in.) or more of face is to be removed and the volume of removal is significant. Explosive blasting is considered to be the most expedient and, in many cases, the most cost-effective means of removal from mass concrete structures. Its primary disadvantage is its potential for damage to the remaining concrete and adjacent structures. Blasting plans typically include drilling holes along removal boundary and employing controlled and sequential blasting methods for the removal. A commonly employed, controlled blasting technique, smooth blasting, uses detonating cord to distribute the blast energy throughout the hole, thereby, avoiding energy concentrations that might damage the concrete that remains. Cushion blasting, a more protective but less used control, is the same as smooth blasting except wet sand is used to fill holes and cushion against the blast effect. The use of saw cuts along removal perimeters is recommended to reduce overbreakage. For removal of vertical faces, a full-depth cut is recommended along the bottom boundary. Sequential blasting techniques allow more delays to be employed per firing. They are recommended for optimizing the amount of explosive detonated per firing while maintaining air-blast pressures, ground vibrations, and fly rock at acceptable levels. When uncertainties regarding the blast plan exist, a pilot test program is recommended to evaluate parameters and ensure acceptable results. Because of dangers inherent in handling and using explosives, all phases of the blasting project should be performed and monitored for compliance with EM 385-1-1.

g. Crushing methods. Crushing methods employ hydraulically powered jaws to crush and remove the concrete.

(1) Boom-mounted mechanical crushers. Boom-mounted crushers (Figure 5-2) are applicable for removing concrete from decks, walls, columns, and other concrete members where the shearing plane depth is 1.8 m (6 ft) or less. This method is typically more applicable for total demolition of a member(s) than for partial removal for rehabilitation or repair. Pulverizing jaw attachments that crush and debond the concrete from the reinforcing steel to facilitate their separation for recycling are available. The major limitations are that the removal boundary must be saw cut to reduce overbreakage, crushing must be started from a free edge or hole made by hand-held breakers or other means, and the exposed reinforcing is damaged beyond reuse. Care must be taken to avoid damaging members that are to support the repair.

(2) Portable mechanical crushers. Portable crushers are applicable for removing concrete from decks, walls, columns, and other concrete members where the shearing plane depth is 300 mm (12 in.) or less. The crusher weighs approximately 45 kg (100 lb) and requires two men to handle. The major limitations are that the removal boundary must be saw cut to reduce overbreakage, crushing must be started from a free edge or hole made by hand-held breakers or other means, and the exposed reinforcing is damaged beyond reuse.

h. Cutting methods. Cutting methods employ full depth perimeter cuts to disjoint concrete for removal as a unit(s). The maximum size of the unit(s) is determined by the load carrying capacities of available lifting and transporting equipment. Cutting methods include abrasive water jets, diamond saws, stitch drilling, and thermal tools.

(1) Abrasive-water-jet cutting. Water-jet systems that include abrasives are applicable for making cutouts through slabs, walls, and other concrete members where

Table 5-1
A General Classification of Concrete Removal Methods Applicable for Concrete Repair

Category	Description	Specific Methods
Blasting	Blasting methods employ rapidly expanding gas confined within a series of boreholes to produce controlled fracture and removal of concrete	Explosive blasting
Crushing	Crushing methods employ hydraulically powered jaws to crush and remove the concrete	Mechanical crushing, boom-mounted Mechanical crushing, portable
Cutting	Cutting methods employ full-depth perimeter cuts to disjoint concrete for removal as a unit or units	Abrasive-water-jet cutting Diamond-blade cutting Diamond-wire cutting Stitch drilling Thermal cutting
Impacting	Impacting methods employ repeated striking of the surface with a mass to fracture and spall the concrete	Mechanical impacting, hand-held Mechanical impacting, boom-mounted Mechanical impacting, spring-action
Milling	Milling methods generally employ abrasion or cavitation-erosion techniques to remove concrete from surfaces	Hydromilling Rotary head milling
Presplitting	Presplitting methods employ wedging forces in a designed pattern of boreholes to produce a controlled cracking of the concrete to facilitate removal of concrete by other means	Presplitting, chemical-expansive agents Presplitting, piston-jack splitter Presplitting, plug-and-feather splitter

Table 5-2
Selection Features and Considerations for Concrete Removal Methods

Category	Method	Features	Considerations
Blasting	Explosive blasting	Method applicable for removal from mass concrete structures	Requires highly skilled personnel for design and execution of blasting plan
		Method is most expedient and, in many cases, the most cost-effective means of removing large volumes where 250 mm (10 in.) or more of face is to be removed	Stringent safety regulations must be complied with regard to the transportation, storage, and use of explosives because of their inherent dangers
		Produces reasonably small size debris that is easily handled	Sequential blasting techniques must be employed to reduce peak blast energies and, thereby, limit damage to surrounding property resulting from air-blast pressure, ground vibration, and fly rock
			Control blasting techniques should be employed to limit damage to concrete that remains
Crushing	Mechanical crushing, boom-mounted	Method applicable for removing concrete from decks, walls, columns, and other concrete members where shearing plane depth is 1.8 m (6 ft) or less	Method is more applicable for total demolition of a concrete member than for removal to rehabilitate or repair
			Boundaries must be saw cut to limit overbreakage
		Boom allows removal from vertical and overhead members	Removal must be started from a free edge or a hole cut in member
		Steel reinforcing can be cut	Exposed reinforcing steel is damaged beyond reuse
		Limited noise and vibration is produced	Production rates vary depending on condition of concrete and amount of reinforcement
		Pulverizing jaw attachment can debond the concrete from the steel reinforcement for purpose of recycling both	
		Method produces relatively small debris that is easily handled	
	Mechanical crushing, portable	Method applicable for removal from decks, walls, and other members where shearing plane depth is 300 mm (12 in.) or less	Requires two men to handle (weighs approximately 45 kg (100 lb))
			Reinforcing steel is damaged beyond reuse
		Method can be used to remove concrete in areas of limited work space	Crushing must be started from a free edge or a hole cut in member
			Boundaries must be saw cut to limit overbreakage

(Sheet 1 of 8)

Table 5-2 (Continued)

Category	Method	Features	Considerations
		Limited noise and vibration is produced	Production rates are low
		Produces small size debris that is easily handled	
Cutting	Abrasive-water-jet cutting	Method applicable for making cutouts through slabs, walls, and other concrete members where access to only one face is feasible and depth of cut is 500 mm (20 in.) or less	Cutting is typically slower and more costly than diamond-blade sawing
			Controlling flow of waste water may be required
		Abrasives enable jet to cut steel reinforcing and hard aggregates	Personnel must wear hearing protection because of the high levels of noise produced
		Irregular and curved cutouts can be made	Additional safety precautions are required because of high water pressures (200 - 340 MPa (30,000 - 50,000 psi)) produced by system
		Cutouts can be made without overcutting corners	
		Cuts can be made flush with adjoining members	
		No heat, vibration, or dust is produced	
		Handling of debris is more efficient as bulk of concrete is removed as units	
	Diamond-blade cutting	Method applicable for making cutouts through slabs, walls, and other concrete members where access to only one face is feasible and depth of cut is 600 mm (24 in.) or less	Selection of the type diamonds and metal bond used in blade segments is based on the type (hardness) and percent of coarse aggregate and on the percent of steel reinforcing in cut
			The higher the percent of steel reinforcement in cuts, the slower and more costly the cutting
		Precision cuts can be made	The harder the aggregate, the slower and more costly the cutting
		No dust or vibration is produced	Controlling flow of waste water may be required
		Handling of debris is more efficient as bulk of concrete is removed as units	Special blades with flush-cut arbors are required to make cuts flush with adjoining members

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Table 5-2 (Continued)

Category	Method	Features	Considerations
	Diamond-wire cutting	Method applicable for making cutouts through concrete where depth of cut is greater than can be economically cut with the diamond-blade saw	The wire saw is a specialty tool that for many jobs will not be as cost effective as other techniques, such as blasting, impacting, and presplitting.
		Cuts can be made through mass concrete and in areas of difficult access	Selection of type diamonds and metal bond used in beads is based on type (hardness) and percent of coarse aggregate and percent of steel reinforcing in cut
		Overcutting of corner can be avoided if cut started from drilled hole at corner	The higher the percent of steel reinforcement in cuts, the slower and more costly the cutting
		No dust or vibration is produced	The harder the aggregate, the slower and more costly the cutting
		Handling of debris is more efficient as bulk of concrete is removed as units	Beads with embedded diamonds last longer, but are more expensive than beads with electroplated diamonds (single layer)
			Wires with beads having embedded diamonds should be of sufficient length to complete cut as replacement will not fit into cut (wear reduces wire diameter and, thereby, cut opening as cutting proceeds).
			Deep cutouts that are formed by three or more boundary cuts may require tapering to avoid binding during removal
			Controlling flow of waste water may be required
	Stitch drilling	Method applicable for making cutouts through concrete members where access to only one face is feasible and depth of cut is greater than can be economically cut by diamond-blade saw	Rotary-percussion drilling is significantly more expedient and economical than diamond-core for nonreinforced concrete
			Diamond-core drilling is more applicable than rotary-percussion drilling for reinforced concrete
		Handling of debris is more efficient as bulk of concrete is removed as units	The greater the percentage of steel reinforcement contained within a cut, the slower and more costly is the cutting
			Depth of cuts is dependent on accuracy of drilling equipment in maintaining overlap between holes with depth and on the diameter of boreholes drilled
			The deeper the cut, the greater borehole diameter required to maintain overlap between adjacent holes and the greater the cost
			Uncut portions between adjacent boreholes will prevent removal

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Table 5-2 (Continued)

Category	Method	Features	Considerations
			Concrete toughness for percussion drilling and aggregate hardness for diamond coring will affect cutting rate and cost
			Personnel must wear hearing protection because of the high levels of noise produced
	Thermal cutting	Method applicable for making cutouts through heavily reinforced decks, beams, walls, and other reinforced members where site conditions allow efficient flow of molten concrete from cuts	Method is of limited commercial availability and is costly
			Remaining concrete has thermal damage with more extensive damage occurring around steel reinforcement
		Method is an effective means of cutting prestressed members	Noise, smoke, and fumes are produced
		Irregular shapes can be cut	Personnel must be protected from heat and hot flying rock produced by cutting operation
		Minimal vibration and dust produced	Additional safety precautions are required because of hazards associated with storage, handling, and use of compressed and flammable gases
		Handling of debris is more efficient as bulk of concrete is removed as units	
Impacting	Mechanical impacting, boom-mounted breaker	Method is applicable for both full and partial depth removals where required production rates are greater than can be economically achieved by the use of hand-held breakers	The blow energy delivered to the concrete should be limited to protect the structure being repaired and surrounding structures from damage resulting from the high cyclic energy generated
			Performance is function of concrete soundness and toughness
		Boom allows concrete to be removed from vertical and overhead members	Productivity is significantly reduced when boom is operated from top of wall because of the operator's limited view of the removal operation
		Boom-mounted breakers are widely available commercially	Care must be taken to avoid damage to supporting members
		Method produces easily handled debris	Concrete that remains may be damaged (microcracking) along with reinforcing steel
			Saw cuts at boundaries should be employed to reduce the occurrence of feathered edges
			Dust is produced
			Personnel must wear hearing protection because of the high levels of noise produced

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Table 5-2 (Continued)

Category	Method	Features	Considerations
	Mechanical impacting, hand-held breaker	Method is applicable for work involving limited volumes of concrete removal and for removal in areas of limited access	Hand-held breakers are generally not applicable for large volumes of removal, except where blow energy must be limited
			Performance is function of concrete soundness and toughness
		Hand-held breakers are widely available commercially	Significant loss in productivity occurs when breaking action is other than downward
		Breakers can be operated by unskilled labor	Removal boundaries will likely require 25-mm (1-in.) deep or greater saw cut to reduce the occurrence of feathered edges
		Method produces relatively small debris that is easily handled	Concrete that remains may be damaged (microcracking)
			Size of breakers for bridge decks is typically limited to 14-kg (30-lb) class for removal above reinforcement and 7-kg (15-lb) class from around reinforcement
			Dust is produced
			Personnel must wear hearing protection because of the high levels of noise produced
	Mechanical impacting, spring-action hammer	Method is applicable for breaking concrete pavement, decks, walls, and other thin members where production rates required are greater than can be economically achieved by the use of hand-held breakers	Method is more applicable for total demolition of a concrete member than for removal to rehabilitate or repair
			The blow energy delivered to the concrete should be limited to protect the structure being repaired and surrounding structures from damage resulting from the high cyclic energy generated
		For decks, hammer can completely punch through slab with each blow leaving only the reinforcing steel	Care must be taken to avoid damage to supporting members
			Performance is function of concrete soundness and toughness
		Method produces easily handled debris	Concrete that remains may be damaged (microcracking) along with reinforcing steel
			Saw cuts at boundaries should be employed to reduce the occurrence of feathered edges
Milling	Hydromilling (Also known as hydrodemolition and water-jet blasting)	Method is applicable for removal of deteriorated concrete from surfaces of decks and walls where removal depth is 150 mm (6 in.) or less	Method is costly
			Productivity is significantly reduced when sound concrete is being removed

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Table 5-2 (Continued)

Category	Method	Features	Considerations
		Method does not damage the concrete that remains	Removal profile will vary with changes in depth of deterioration
		Steel reinforcing is left undamaged for reuse	Holes through member (blowouts) are a common occurrence when removal is near full depth of member
		Method produces easily handled, aggregate-size debris	Repair of blowouts requires additional material and form work, thereby, increasing repair time and cost
			Method requires large source of potable water (the water demand for some units exceeds 4,000 L/hr (1,000 gal/hr))
			Laitence coating that is deposited on remaining surfaces during removal should be washed from surface before coating dries
			Flow of waste water may have to be controlled
			An environmental impact statement will be required if waste water is to enter a waterway
			Personnel must wear hearing protection because of the high level of noise produced
			Fly rock is produced
			Additional safety requirements are required because of the high pressures (100 - 300-MPa (16,000 - 40,000-psi) range) produced by the system
	Rotary-head milling	Method is applicable for removing deteriorated concrete from mass structures	Removal is limited to concrete outside structural steel reinforcement
		Method is applicable for removing deteriorated concrete cover from reinforced members such as pavements and decks where it is unlikely that the reinforcement will be contacted	Significant loss of productivity occurs in sound concrete
			Productivity is significantly reduced when boom is operated from top of wall as operator's view of cutting is very limited
			Concrete that remains may be damaged (microcracking)
		Boom allows removal from vertical and overhead surfaces	Skid loader units typically mill a more uniform removal profile than other rotary-head and water-jet units

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Table 5-2 (Continued)

Category	Method	Features	Considerations
		Concrete containing wire mesh can be cut without significant losses in productivity	Noise, vibration, and dust are produced
		Method produces relatively small debris that is easily handled	
Presplitting	Chemical presplitting, expansive agents	Method is applicable for presplitting concrete members where depth of boreholes is 10 times borehole diameter or greater	Personnel must be restricted from presplitting area during early hours of product hydration as material has the potential to blow out of boreholes and cause injury
			Presplitting with expansive agents is typically costly
		Expansive products can be used to produce vertical presplitting planes of significant depth	Expansive products that are prills or become slurries when water is added are best used in gravity-filled, vertical, or near-vertical holes. A liner may be required to contain the expansive material in holes drilled into concrete with extensive cracks
		Some products form a clay-type material when mixed with water that allows the material to be packed into horizontal holes	Products are limited to a specific temperature range
			Rotary-head milling or mechanical-impacting methods will be required to complete removal
		No vibration, noise, or flying rock is produced other than that produced by the drilling of boreholes and the secondary breakage method	Development of presplitting plane is significantly decreased by presence of reinforcing steel normal to plane
			Loss of control of presplitting plane can result if boreholes are too far apart or holes are located in severely deteriorated concrete
	Mechanical presplitting, piston-jack splitter	Method is applicable for presplitting more massive concrete structures where 250 mm (10 in.) or more of face is to be removed and presplitting requires boreholes of a depth greater than can be used by plug-and-feather splitters	Large-diameter (90-mm (3-1/2-in.)) boreholes are required that increase cost
			Splitters are typically used in pairs to control presplitting plane
			Hand-held breakers and pry bars are typically required to complete removal
		Splitter can be reinserted into boreholes to continue removal for full depth of holes	Development of presplitting plane is significantly decreased by presence of reinforcing steel normal to presplit plane
		Splitter can be used in areas of difficult access	Loss of control of presplitting plane can result if boreholes are too far apart or holes are located in severely deteriorated concrete

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Table 5-2 (Concluded)

Category	Method	Features	Considerations
			Availability of splitters is limited in the U.S.
		No vibration, noise, or flying rock is produced other than that produced by the drilling of boreholes and the secondary breakage method	
	Mechanical presplitting, plug-and-feather splitter	Method applicable for presplitting slabs, walls, and other concrete members where presplitting depth is 4 ft or less	Splitter can not be reinserted into boreholes to continue presplitting after presplit section has been removed, as the body of the tool is wider than the borehole
		Method typically less costly than cutting methods	Development of presplitting plane in direction of borehole depth is limited
		Initiation of direction of presplitting can be controlled by orientation of plug and feathers	Development of presplitting plane is significantly decreased by presences of reinforcing steel normal to plane
			Secondary means of breakage will typically be required to complete removal
		Splitters can be used in areas of limited access	
			Loss of control of presplitting plane can result if boreholes are too far apart or holes are located in severely deteriorated concrete
		Limited skills required by operator	
		No vibration, noise, or flying rock is produced other than that produced by the drilling of boreholes and the secondary breakage method	

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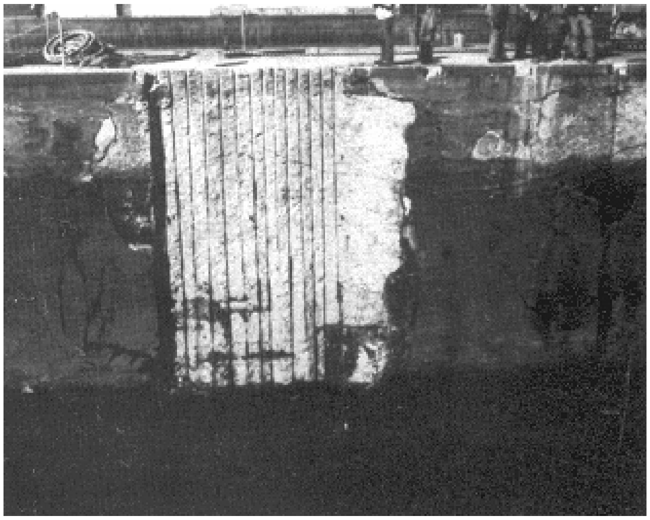

Figure 5-1. Surface removal of deteriorated concrete by explosive blasting

Figure 5-2. Boom-mounted concrete crusher

access to only one face is feasible and depth of cut is 500 mm (20 in.) or less. The abrasives enable the jet to cut steel reinforcing and hard aggregates. One major limitation of abrasive-water-jet cutting is that it is typically slower and more costly than diamond-blade sawing. Personnel must wear hearing protection because of the high levels of noise produced. Additional safety precautions are required because of high water pressures (200 to 340 MPa (30,000 to 50,000 psi)) produced by the system. Controlling flow of waste water may be required.

(2) Diamond-blade cutting. Diamond-blade cutting (Figure 5-3) is applicable for making cutouts through slabs, walls, and other concrete members where access to only one face is feasible and depth of cut is 600 mm (24 in.) or less. Blade selection is a function of the type (hardness) and percent of coarse aggregate and on the percent of steel reinforcing. The harder the coarse aggregate and the higher the percentage of steel reinforcement in the cut, the slower and more costly the cutting. Diamond-blade cutting is also applicable for making cuts along removal boundaries to reduce feathered edges in support of other methods.

(3) Diamond-wire cutting. Diamond-wire cutting (Figure 5-4) is applicable for making cutouts through concrete where the depth of cut is greater than can be economically cut with a diamond-blade saw. Cuts can be made through mass concrete and in areas of difficult access. The cutting wire is a continuous loop of multistrand wire cable strung with steel beads containing either embedded or electroplated diamonds. Beads with embedded diamonds last longer but are more expensive than beads with electroplated diamonds (single layer). Wires with beads having embedded diamonds should be of sufficient length to complete the cut as replacement wire will not fit into the cut (wear reduces wire diameter and, thereby, cut opening as cutting proceeds). The wire saw is a specialty tool that for many jobs will not be as

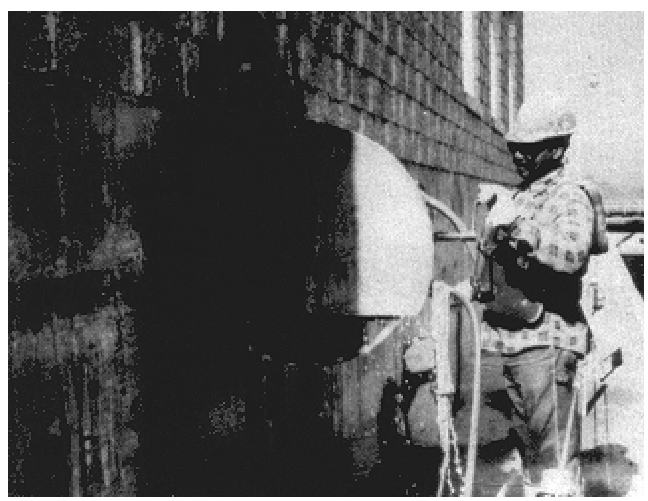

Figure 5-3. Diamond-blade saw

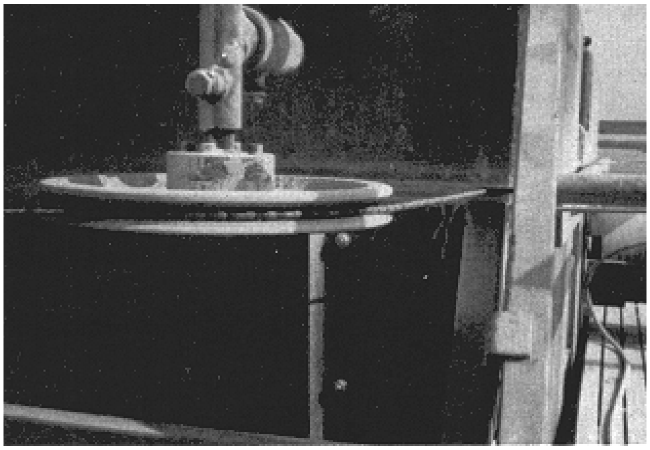

Figure 5-4. Diamond-wire saw

cost effective as other methods, such as blasting, impacting, and presplitting.

(4) Stitch cutting. Method applicable for making cutouts through concrete members where access to only one face is feasible and depth of cut is greater than can be economically cut by diamond-blade saw. Depth of cuts is dependent on the accuracy of drilling equipment in maintaining overlap between holes with depth and on the diameter of boreholes drilled. If overlap between holes is not maintained, uncut portions of concrete that will prevent removal remain between adjacent boreholes. If opposite faces of a member can be accessed, diamond-wire cutting will likely be more applicable. Concrete toughness for percussion drilling and aggregate hardness for diamond coring will affect the cutting rate and the cost.

(5) Thermal cutting. Thermal-cutting methods are applicable for making cutouts through heavily reinforced decks, beams, walls, and other reinforced members where site conditions allow efficient flow of molten concrete from cuts. Flame tools (Figure 5-5) are typically employed for cutting depths of 600 mm (24 in.) or less, and lances (Figure 5-6), for greater depths. Thermal cutting tools are of limited commercial availability and are costly to use. The concrete that remains has a layer of thermal damage with more extensive damage occurring around steel reinforcement. Personnel must be protected from heat and hot flying rock produced by the cutting operation. Additional safety precautions are required because of the hazards associated with the storage, handling, and use of compressed and flammable gases. The method is also applicable for the demolition of prestressed members.

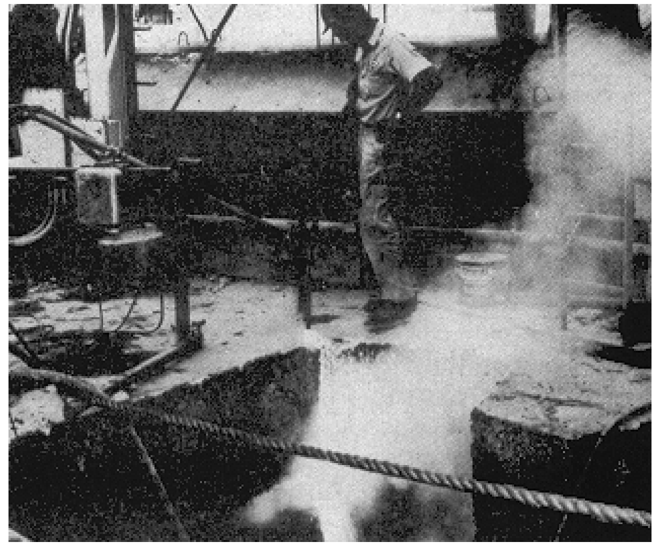

Figure 5-5. Powder torch

Figure 5-6. Thermal lance

i. Impacting methods. Impacting methods generally employ the repeated striking of a concrete surface with a mass to fracture and spall the concrete. Impact methods are sometimes used in a manner similar to cutting methods to disjoint the concrete for removal as a unit(s) by breaking out concrete along the removal perimeter of thin members such as slabs, pavements, decks, and walls. Any reinforcing steel along the perimeter would have to be cut to complete the disjointment. Impacting methods include the boom-mounted and hand-held breakers and spring-action hammers.

(1) Boom-mounted breakers. Boom-mounted impact breakers are applicable for both full- and partial-depth removals where production rates required are greater than can be economically achieved by the use of hand-held breakers. The boom-mounted breakers are somewhat similar to the hand-held breakers except that they are considerably more massive. The tool is normally attached to the hydraulically operated arm of a backhoe or excavator (Figure 5-7) and can be operated by compressed air or hydraulic pressure. The reach of the hydraulic arm enables the tool to be used on walls at a considerable distance above or below the level of the machine. Boom-mounted breakers are a highly productive means of removing concrete. However, the blow energy delivered to the concrete should be limited to protect the structure being repaired and surrounding structures from damage resulting from the high cyclic energy generated. Saw cuts should be employed at removal boundaries to reduce the occurrence of feathered edges. The concrete that remains may be damaged (microcracking) along with the exposed reinforcing steel. Washing the concrete surface with a high-pressure (138 MPa (20,000 psi) minimum) water jet may remove some of the microfractured concrete.

Figure 5-7. Boom-mounted breaker

(2) Spring-action hammers. Spring-action hammers (sometimes referred to as mechanical sledgehammers) are boom-mounted tools that are applicable for breaking concrete pavements, decks, walls, and other thin members where production rates required are greater than can be economically achieved with the use of hand-held breakers. Hammers are more applicable for total demolition of a concrete member than for removal to rehabilitate or repair. The arm of the hammer is hydraulically powered, and the impact head is spring powered. The spring is compressed by the downward movement of the arm of the backhoe or excavator and its energy released just prior to impact. There are truck units available that make it easier to move between projects. The operation of the hammer and advancement of the truck during removal are controlled from a cab at the rear of truck (Figure 5-8). The blow energy delivered to the concrete should be limited to protect the structure being repaired and surrounding structures from damage caused by the high cyclic energy generated. Saw cuts should be employed at removal boundaries to reduce the occurrence of feathered edges. The concrete that remains may be damaged (microcracking) along with the exposed reinforcing steel.

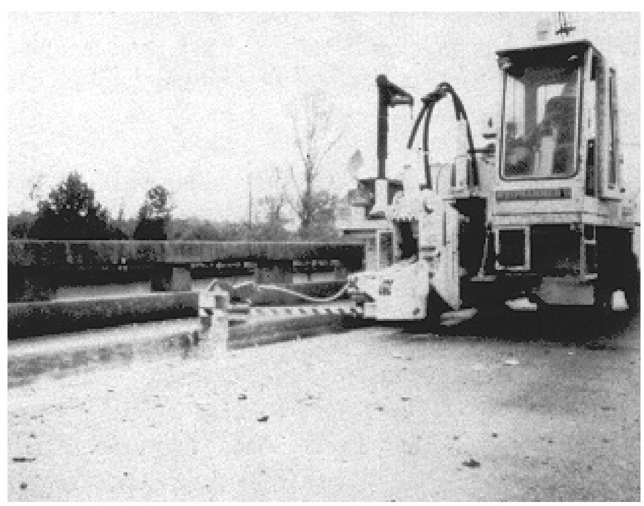

Figure 5-8. Spring-action hammer (mechanical sledgehammer)

(3) Hand-held impact breakers. Hand-held impact breakers (Figure 5-9) are applicable for work involving limited volumes of concrete removal and for removal in areas of limited access. Hand-held breakers are sometimes applicable for large volumes of removal where blow energy must be limited or the concrete is highly deteriorated. Breakers are also suitable for use in support of other means of removal. Hand-held breakers are powered by one of four means: compressed air, hydraulic pressure, self-contained gasoline engine, or self-contained electric motor.

j. Milling. Milling methods generally employ impact-abrasion or cavitation-erosion techniques to remove concrete from surfaces. Methods include hydromilling and rotary-head milling.

(1) Hydromilling. Hydromilling (also known as hydrodemolition and water-jet blasting) is applicable for removal of deteriorated concrete from surfaces of decks (Figure 5-10) and walls where removal depth is 150 mm (6 in.) or less. This method does not damage the concrete that remains and leaves the steel reinforcing undamaged for reuse in the replacement concrete. Its major limitations are that the method is costly, productivity is significantly reduced when sound concrete is being removed, and the removal profile varies with changes in depth of deterioration. Holes through members (blowouts) are a common occurrence when removal is near full depth of a member. This method requires a large source of potable water (the water demand for some units exceeds 4,000 L/hr (1,000 gal/hr)). An environmental impact statement is required if waste water is to enter a waterway. Personnel must wear hearing protection because of the high level of noise produced. Flying rock is produced. Laitence coating that is deposited on remaining surfaces during removal should be washed from the surfaces before the coating dries.

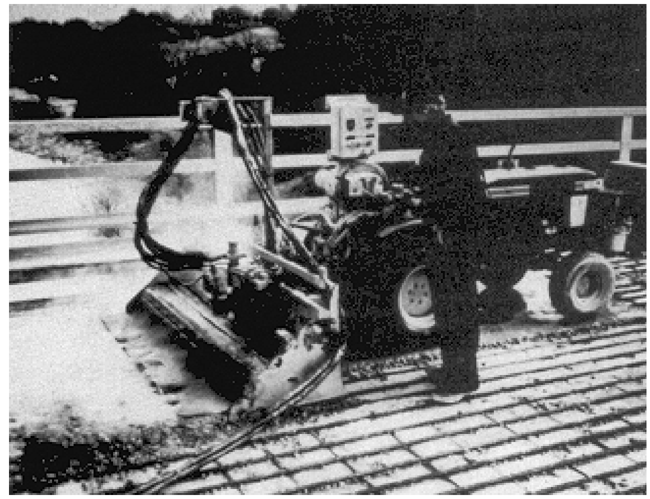

Figure 5-10. Hydromilling (water-jet blasting)

(2) Rotary-head milling. Method is applicable for removing deteriorated concrete from mass structures (Figure 5-11) and for removing deteriorated concrete cover from reinforced members such as pavements and decks where its contact with the reinforcement is unlikely. Removal is limited to concrete outside structural steel reinforcement. Significant loss of productivity occurs in sound concrete. For concrete having a compressive strength of 55 MPa (8,000 psi) or greater, rotary-head milling is not applicable. Concrete that remains may be

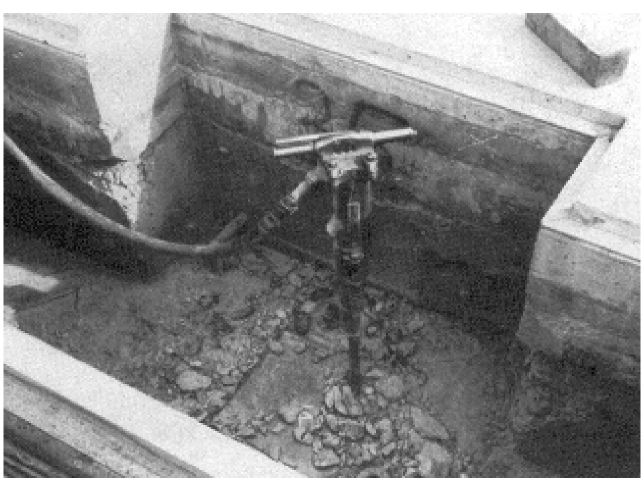

Figure 5-9. Hand-held breaker

Figure 5-11. Rotary-head milling

damaged (microcracking). Skid loader units typically mill a more uniform removal profile than other rotary-head and water-jet units.

k. Presplitting. Presplitting methods employ wedging forces in a designed pattern of boreholes to produce a controlled cracking of the concrete to facilitate removal of concrete by other means. The pattern, spacing, and depth of the boreholes affect the direction and extent of the presplitting planes. Presplitting methods include chemical-expansive agents and hydraulic splitters. Note: for all presplitting methods, the development of a presplitting plane is significantly decreased by the presence of reinforcing steel normal to the plane, and the loss of control of a presplitting plane can result if boreholes are too far apart or holes are located in severely deteriorated concrete.

(1) Chemical presplitting, expansive agents. The presplitting method that uses chemical-expansive agents (Figure 5-12) is applicable for removal from slabs, walls, and other concrete members where depth of boreholes is 10 times the borehole diameter or greater. It is especially applicable for situations requiring the development of vertical presplitting planes of significant depth. The main disadvantages of employing expansive agents are cost and application-temperature limitations. Personnel must be restricted from the presplitting area during early hours of product hydration as the material has the potential to blow out of boreholes and cause injury. Expansive products that are prills or become slurries when water is added are best used in gravity filled, vertical or near-vertical holes. Some products form a clay-type material when mixed with water that allows the material to be packed into horizontal holes. The newer expansive agents produce presplitting planes in 4 hr or less. Rotary-head milling or mechanical-impacting methods will be required to complete removal.

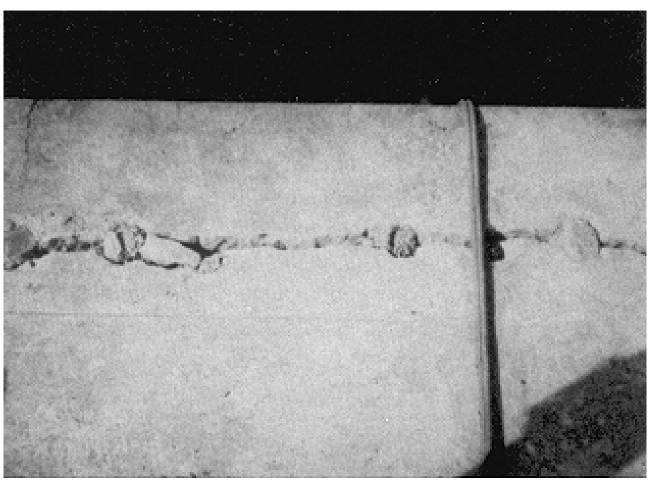

Figure 5-12. Presplitting using chemical-expansive agent

(2) Mechanical presplitting, piston-jack splitter. Piston-jack splitters (Figure 5-13) are applicable for presplitting more massive concrete structures where 250 mm (10 in.) or more of the face is to be removed and presplitting requires boreholes of a depth greater than can be used by plug-and-feather splitters. The piston-jack splitters initiate presplitting from opposite sides of a borehole, normal to the direction of piston movement. The splitters are reinserted into boreholes to continue removal. Process is repeated for full depth of holes. Splitters are typically used in pairs to control the presplitting plane. The primary disadvantages of this method are the cost of drilling the required 90-mm (3-1/2-in.)-diam boreholes and the limited availability of piston-jack devices in the United States.

(3) Mechanical presplitting, plug-feather splitter. Plug-and-feather splitters (Figure 5-14) are applicable for presplitting slabs, walls, and other concrete members where the presplitting depth is 1.2 m (4 ft) or less. Initiation of direction of presplitting can be controlled by orientation of plug and feathers. The primary limitation of these splitters is that they can not be reinserted into boreholes to continue presplitting after the presplit section has been removed, since the body of the tool is wider than the borehole.

l. Monitoring removal operations. The extent of damage to the concrete that remains after a removal

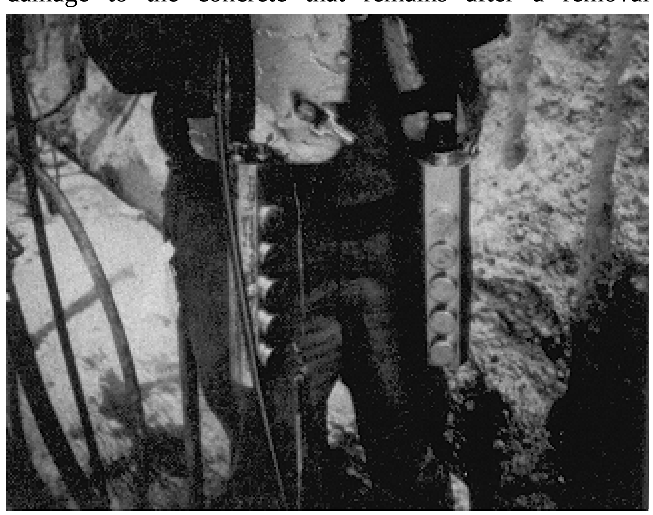

Figure 5-13. Piston-jack splitter

method has been employed is usually evaluated by visual inspection of the remaining surfaces. For a more detailed evaluation, a monitoring program can be implemented. The program may consist of taking cores before and after removal operations, making visual and petrographic examinations, and conducting pulse-velocity and ultimate-strength tests of the cores. A pulse-velocity study of the in situ concrete may also be desired. A comparison of the data obtained before and after removal operations could then be used to determine the relative condition of remaining concrete and to identify damage resulting from the removal method employed. To further document the extent of damage, an instrumentation program may be required.

m. Quantity of concrete removal. In most concrete repair projects, all damaged or deteriorated concrete should be removed. However, estimating the quantity of concrete to be removed prior to a repair is not an easy task, especially if it is intended that only unsound concrete be removed. Substantial overruns have been common. Errors in estimating the removal quantity can be minimized by a thorough condition survey as close as possible to the time the repair work is executed. When, by necessity, the condition survey is done far in advance of the repair work, the estimated quantities should be increased to account for continued deterioration.

n. Vibration and damage control. Blasting operations in or adjacent to buildings, structures, or other facilities should be carefully planned with full consideration of all forces and conditions involved. Appropriate vibration and damage control should be established in accordance with EM 385-1-1.

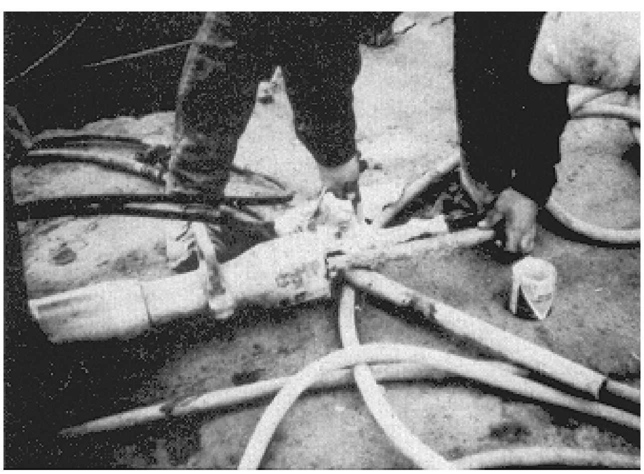

Figure 5-14. Plug-and-feather splitter

5-3. Preparation for Repair

One of the most important steps in the repair or rehabilitation of a concrete structure is the preparation of the surface to be repaired. The repair will only be as good as the surface preparation, regardless of the nature or sophistication (expense) of the repair material. For reinforced concrete, repairs must include proper preparation of the reinforcing steel to develop bond with the replacement concrete to ensure desired behavior in the structure. Preparation of concrete and reinforcing steel after removal of deteriorated concrete and anchor systems are discussed in the following.

a. Concrete surfaces.

(1) General considerations.

(a) The desired condition of the concrete surface immediately before beginning a repair depends somewhat on the type of repair being undertaken. For example, a project involving the application of a penetrating sealer may require only a broom-cleaned dry surface, whereas another project involving the placement of a latex-modified concrete overlay may require a sound, clean, rough-textured, wet surface. However, the desired condition of the prepared surface for most repairs will be sound, clean, rough-textured, and dry.

(b) Concrete is removed to a fixed depth for many maintenance and repair projects, leaving local areas of deteriorated concrete that must be removed as part of the surface preparation work. This secondary removal is typically accomplished with hand-held impact tools. Boom-mounted breakers and rotary-head milling are frequently used to remove nonreinforced concrete where extensive amounts of secondary removal are required.

(c) In most concrete repair projects, all damaged or deteriorated material should be removed. However, it is not always easy to determine when all such material has been removed. The best recommendation is to continue to remove material until aggregate particles are being broken rather than simply being removed from the cement matrix.

(d) Whenever concrete is removed with impact tools or by rotary-head milling, there is the potential for very small-scale damage to the surface of the concrete left in place. Unless this damaged layer is removed, the replacement material will suffer what appears to be a bond failure. Thus, a perfectly sound and acceptable replacement material may fail because of improper surface preparation.

(e) Following secondary removal, all exposed surfaces should be prepared with dry or wet sandblasting or water-jet blasting to remove any damaged surface material. Surfaces that were exposed by water-jet blasting will typically not require this surface preparation.

(2) Methods of surface preparation.

(a) Chemical cleaning. In cases in which concrete is contaminated with oil, grease, or dirt, these contaminants must be removed prior to placement of repair materials. Detergents, trisodium phosphate, and various other proprietary concrete cleaners are available for this work. It is also important that all traces of the cleaning agent be removed after the contaminating material is removed. Solvents should not be used to clean concrete since they dissolve the contaminants and carry them deeper into the concrete. Muriatic acid, commonly used to etch concrete surfaces, is relatively ineffective for removing grease or oil.

(b) Mechanical cleaning. There is a variety of mechanical devices available for cleaning concrete surfaces. These devices include scabblers, scarifiers, and impact tools. Depending upon the hammer heads used or the nature of the abrasive material, a variety of degrees of surface preparation may be achieved. After use of one of these methods, it may be necessary to use another means (waterjetting or wet sandblasting) for final cleaning of the surface.

(c) Shot blasting. Steel shot blasting produces a nearly uniform profile that is ideally suited for thin overlay repairs. It can produce light-brush blasting to 6-mm (1/4-in.)-depth removal depending on the size shot selected and the duration of the removal effort. The debris is vacuumed up and retained by the unit. Steel shot blasting leaves the surface dry for immediate application of a bonding agent, coating, or overlay.

(d) Blast cleaning. Blast cleaning includes wet and dry sandblasting, and water jetting. When sandblasting is used, the air source must be equipped with an effective oil trap to prevent contamination of the concrete surface during the cleaning operation. Water-jetting equipment with operating pressures of 40 to 70 MPa (6,000 to 10,000 psi) is commercially available for cleaning concrete. This equipment is very effective when used as the final step in surface preparation.

(e) Acid etching. Acid etching of concrete surfaces has long been used to remove laitance and normal amounts of dirt. The acid will remove enough cement paste to provide a roughened surface which will improve the bond of replacement materials. ACI 515.1R recommends that acid etching be used only when no alternative means of surface preparation can be used. The preparation methods described earlier are believed to be more effective than acid treatment. If acid is used, the surface should be cleaned of grease and oil with appropriate agents, and the cleaning agents should be rinsed off the surface before the acid is added. Acid is then added at a rate of approximately 1 L/sq m (1 qt/sq yd), and it should be worked into the concrete surface with a stiff brush or broom. When the foaming stops (3 to 5 min), the acid should be rinsed off, and brooms should be used to remove reaction products and any loosened particles. The surface should be checked with litmus or pH paper to determine that all acid has been removed.

(f) Bonding agents. The general guidance is that small thin patches (less than 50 mm (2 in.) thick) should receive a bonding coat while thicker replacements probably do not require any bonding agent. Excellent bond of fresh-to-hardened concrete can be achieved with proper surface preparation and without the use of bonding agents. The most common bonding agents are simply grout mixtures of cement slurry or equal volumes of portland cement and fine aggregate mixed with water to the consistency of thick cream. The grout must be worked into the surface with stiff brooms or brushes. The grout should not be allowed to dry out before the concrete is placed. A maximum distance of 1.5 m (5 ft) or a period of 10 min ahead of the concrete placement are typical figures used in the specification. There is a wide variety of epoxy and other polymer bonding agents available. If one of these products is used, the manufacturer's recommendations must be followed. Improperly applied bonding agents can actually reduce bond.

b. Reinforcing steel.

(1) General considerations.

(a) By far, the most frequent cause of damage to reinforcing steel is corrosion. Other possible causes of damage are fire and chemical attack. The same basic preparation and repair procedures may be used for all of these causes of damage.

(b) Once the cause and the magnitude of the damage have been determined, it remains to expose the steel, evaluate its structural condition, and prepare the reinforcement for the placement of the repair material. Proper steps to prepare the reinforcement will ensure that the repair method is a permanent solution rather than a temporary solution that will deteriorate in a short period of time.

(2) Removal of concrete surrounding reinforcing steel. The first step in preparing reinforcing steel for repair is the removal of the deteriorated concrete surrounding the steel. Usually, the deteriorated concrete above the top reinforcement can be removed with a jackhammer. For this purpose, a light (14-kg (30-lb)) hammer should be sufficient and should not significantly damage sound concrete at the periphery of the damaged area. Extreme care should be exercised to ensure that further damage to the reinforcing steel is not inflicted in the process of removing the deteriorated concrete. Jackhammers can heavily damage reinforcing steel if the hammer is used without knowledge of the location of the steel. For this reason, a copy of the structural drawings should be used to determine where the reinforcement is located and its size, and a pathometer should be used to determine the depth of the steel in the concrete. Once the larger pieces of the damaged concrete have been removed, a (7-kg (15-lb)) chipping hammer should be used to remove the concrete in the vicinity of the reinforcement. Water-jet blasting may also be used for removal of concrete surrounding the reinforcing steel.

(3) How much concrete to remove. Obviously, all weak, damaged, and easily removable concrete should be chipped away. If more than one-half of the perimeter of the bar has been exposed during removal of deteriorated concrete, then concrete removal should continue to give a clear space behind the reinforcing steel of 6 mm (1/4 in.) plus the dimension of the maximum size aggregate. If less than one-half of the perimeter of a bar is exposed after concrete removal, the bar should be inspected, cleaned as necessary, and then repairs should proceed without further concrete removal. However, if inspection indicates that a bar or bars must be replaced, concrete must be removed to give the clear space indicated above.

(4) Inspection of reinforcing steel. Once deteriorated concrete has been removed, reinforcing steel should be carefully inspected. If the cross-sectional area of a bar has been significantly reduced by corrosion or other means, the steel may have to be replaced. If there is any question concerning the ability of the steel to perform as designed, a structural engineer should be consulted. Project specifications should include a provision whereby decisions concerning repair versus replacement of reinforcing steel can be made during the project as the steel is exposed.

(5) Replacing reinforcing steel. The easiest method of replacing reinforcement is to cut out the damaged area and splice in replacement bars. A conventional lap splice is preferred. The requirements for length of lap should conform to the requirements of ACI 318. If mechanical splices are considered, their use should be approved by a structural engineer. If a welded splice is used, it should also be performed in accordance with ACI 318. Butt welding should be avoided because of the high degree of skill required to perform a full penetration weld. High-strength steel should not be welded.

(6) Cleaning reinforcing steel.

(a) When it has been determined that the steel does not need replacing, the steel should be thoroughly cleaned of all loose rust and foreign matter before the replacement concrete is placed. For limited areas, wire brushing or other hand methods of cleaning are acceptable. For larger areas, dry sandblasting is the preferred method. The sandblasting must remove all the rust from the underside of the reinforcing bars. Normally, the underside is not directly hit by the high-pressure sand particles and must rely on rebound force as the sand comes off the substrate concrete surface. The operator must be suited with a respiratory device because of the health hazard associated with dry blasting.

(b) The type of air compressor used in conjunction with sandblasting is important. When the steel is cleaned and loose particles are blown out of the patch area after cleaning, it is important that neither the reinforcing steel nor the concrete substrate surface be contaminated with oil from the compressor. For this reason, either an oil-free compressor or one that has a good oil trap must be used.

(c) Alternative methods of cleaning the steel are wet sandblasting or water-jet blasting. These methods are not as good as dry sandblasting, because they provide the water and oxygen necessary to begin the corrosion process again once the steel has been cleaned.

(d) There is always the possibility that freshly cleaned reinforcing steel will rust between the time it is cleaned and the time that the next concrete is placed. If the rust that forms is tightly bonded to the steel, there is no need to take further action. If the rust is loosely bonded or in any other way may inhibit bonding between the steel and the concrete, the reinforcing bars must be cleaned again immediately before concrete placement.

c. Anchors. Dowels may be required in some situations to anchor the repair material to the existing concrete substrate. ACI 355.1R summarizes anchor types and provides an overview of anchor performance and failure modes under various loading conditions. It also covers design and construction considerations and summarizes existing requirements in codes and specifications. Design criteria for anchoring relatively thin sections (less than 0.8 m (2.5 ft)) of cast-in-place concrete are described in Section 8-1. Anchor installation underwater is discussed in Section 8-6. Most of the anchors used in repair are installed in holes drilled in the concrete substrate and can be classified as either bonded or expansion anchors.

(1) Drilling. Anchor holes should be drilled with rotary carbide-tipped or diamond-studded bits or hand-hammered star drill bits. Drilling with a jackhammer is not recommended because of the damage that results immediately around the hole from the impact. Holes should be cleaned with compressed air and plugged with a rag or other suitable material until time for anchor installation. Holes should be inspected for proper location, diameter, depth, and cleanliness prior to installation of anchors.

(2) Bonded anchors. Bonded anchors are headed or headless bolts, threaded rods, or deformed reinforcing bars. Bonded anchors are classified as either grouted anchors or chemical anchors.

(a) Grouted anchors are embedded in predrilled holes with neat portland cement, portland cement and sand, or other commercially available premixed grout. An expansive grout additive and accelerator are commonly used with cementitious grouts.

(b) Chemical anchors are embedded in predrilled holes with two-component polyesters, vinylesters, or epoxies. The chemicals are available in four forms: glass capsules, plastic cartridges, tubes (“sausages”), or bulk. Following insertion into the hole, the glass capsules and tubes are both broken and their contents mixed by insertion and spinning of the anchor. The plastic cartridges are used with a dispenser and a static mixing nozzle to mix the two components as they are placed in the drill hole. Bulk systems are predominately epoxies which are mixed in a pot, or pumped through a mixer and injected into the hole after which the anchor is immediately inserted.

(c) Some chemical grouts creep under sustained loading, and some lose their strength when exposed to temperatures over 50 °C (120 °F). Creep tests were conducted, as part of the REMR Research Program, by subjecting anchors to sustained loads of 60 percent of their yield strength for 6 months. The slippage exhibited by anchors embedded in polyester resin was approximately 30 times higher than that of anchors embedded in portland-cement (Best and McDonald 1990b).

(3) Expansion anchors. Expansion anchors are designed to be inserted into predrilled holes and then expanded by either tightening a nut, hammering the anchor, or expanding into an undercut in the concrete. Expansion anchors that rely on side point contact to create frictional resistance should not be used where anchors are subjected to vibratory loads. Some wedge-type anchors perform poorly when subjected to impact loads. Undercut anchors are suitable for dynamic and impact loads.

(4) Load tests. Following installation, randomly selected anchors should be tested to ensure compliance with the specifications. In some field tests, anchors have exhibited significant slippage prior to achieving the desired tensile capacity. Therefore, it may be desirable to specify a maximum displacement in addition to the minimum load capacity.