REMR Technical Note CS-MR-1.14

Concrete Removal Techniques: Selection

Purpose

To provide guidance for selecting concrete removal technique(s). (Additional information on specific concrete removal techniques is provided in REMR Technical Notes SC-MR-1.1 - SC-MR-1.11.)

Introduction

Selection of the best concrete removal technique to benefit the maintenance or repair needs of a project is dependent on many parameters, such as cost, site restrictions, time restraints, magnitude of removal, and composition and condition of the concrete to be removed. Often there are several techniques that appear applicable for a removal effort. In these cases, the final selection is based on cost. Note that the cost of removal can vary widely between like projects and depends on the expertise and equipment available to the contractor or Government at the time.

General Considerations

A repair technique requiring no concrete removal should be considered for situations where the deteriorated or 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 in the Pittsburgh District by placing an unbonded concrete overlay without removing the deteriorated concrete. Similarly, the cost of concrete removal was saved by installing precast concrete panels over deteriorated concrete on the backside of river walls at Lockport Lock in the Rock Island District and Troy Lock and Dam in the New York District.

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. Since sound concrete is removed along with the deteriorated concrete, this approach increases the difficulty of removal. As the productivity of removal techniques varies significantly depending on the soundness of the concrete, information describing the condition and properties of the concrete should be collected and reviewed prior to the selection of removal technique(s). The cost of removal and repair should be compared with the cost of total demolition and replacement of the member or structure if the damage is extensive.

If work is to be contracted, information describing the condition and properties of the concrete must be made available at the time of bid advertisement 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, and compressive and splitting-tensile strengths of concrete. When uncertainties exist regarding the condition of the concrete or the performance of the removal technique(s) selected, an onsite demonstration should be implemented to test production rates and ensure acceptable results before work is begun.

Environment

An evaluation to assess the effects of debris from concrete removal entering a river, stream, or waterway is required before a contract is awarded. The effects vary from project to project and depend to a great extent on the size and environmental condition of the waterway and on the quantity of 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 is considered to have a negligible impact on the waterway. When individual particles are of sufficient size, debris can be placed in open water to construct a fish attractor reef as a means of disposal. Recycling of concrete debris should be considered as an alternative to landfill disposal.

Removal Techniques

Concrete removal techniques are outlined in Tables 1 and 2. These techniques have been grouped into six general categories, as shown in Table 1. Selection features and general considerations for each removal technique have been summarized in Table 2.

Summary

For a repair and rehabilitation project in which removal of concrete is required, all applicable concrete removal techniques should be evaluated. The principal factors to be considered should include, but are not limited to, (a) impact of removal debris on the environment, (b) cost, (c) removal rates, (d) quantity and quality of the concrete to be removed, (e) potential for damage to the concrete that remains, and (f) compliance with site restrictions, such as acceptable levels of noise and ground vibration. All acceptable removal techniques should be specified in the appropriate specifications. A description of the concrete should be made available at the time bids are being solicited to reduce the potential for a costly claim based on "differing site conditions."

Table 1
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, boom-mounted mechanical impacting, hand-held 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 2
Selection Features and Considerations for Concrete Removal Methods

Category	Methods	Features	Considerations
Blasting	Explosive blasting	Method applicable for removal from mass concrete structures 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 Produces reasonably small size debris that is easily handled	Requires highly skilled personnel for design and exectution of blasting plan Stringent safety regulations must be complied with regarding transportation, storage, and use of explosives due to their inherent dangers 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, wall columns, and other concrete members where shearing plane depth is 1.8 m (6 ft) or less Boom allows removal from vertical and overhead members Steel reinforcing can be cut Limited noise and vibration is produced Pulverizing jaw attachment can debond the concrete from the steel reinforcement for purpose of recycling both Produces relatively small, easily handled debris	Method is more applicable for total demolition of a concrete member rather than for removal to rehabilitate or repair Boundaries must be sawcut to limit overbreakage Removal must be started from a free edge or a hole cut in member Exposed reinforcing steel is damaged beyond reuse Production rates vary depending on condition of concrete and amount of reinforcement
	Mechanical crushing, portable	Method applicable for removal from decks, walls, and other members where shearing plane depth is 300 mm (12 in.) or less Method can be used to remove concrete in areas of limited work space Produces limited noise and vibration Produces small size debris that is easily handled	Requires two men to handle (weighs approximately 54 kg (100 lb) Reinforcing steel is damaged beyond reuse Crushing must be started from a free edge or a hole cut in member Boundaries must be sawcut to limit overbreakage Production rates are low

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Table 2 (Continued)

Category	Method	Features	Considerations
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 Abrasives enable jet to cut steel reinforcing and hard aggregates Irregular and curved cutouts can be made 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	Cutting is typically slower and more costly than diamond blade sawing Controlling flow of wastewater may be required Personnel must wear hearing protection due to the high levels of noise produced Additional safety precautions are required due to high water pressures; 200 to 340 MPa (30,000 to 50,000 psi) produced by system
	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 Precision cuts may be made No dust or vibration is produced Handling of debris is more efficient as bulk of concrete removed as units	Selection of the type of diamonds and metal bond used in blade segments is based on the type (hardness) and percent of coarse aggregate and on the percent steel reinforcing in cut The higher the percent of steel reinforcement in cuts, the slower and more costly the cutting The harder the aggregate, the slower and more costly the cutting Controlling flow of wastewater may be required Personnel must wear hearing protection due to the high levels of noise produced Special blades with flush cut arbors are required to make cuts flush with adjoining members
	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 (Continued)

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Table 2 (Continued,

Category	Method	Features	Considerations
Cutting (Continued)	Diamond wire cutting (Continued)	Cuts can be made through mass concrete and in areas of difficult access Overcutting of corner can be avoided if cut started from drilled hole at corner No dust or vibration is produced Handling of debris is more efficient as bulk of concrete removed as units	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 The higher the percent of steel reinforcement in cuts, the slower and more costly the cutting The harder the aggregate, the slower and more costly the cutting Beads with embedded diamonds last longer, but are more expensive than beads with electroplated diamonds (single layer) For wires with beads having embedded diamonds, wire 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 Personnel must wear hearing protection due to the high levels of noise produced Controlling flow of wastewater may be required
	Stitch drilling	Method applicable for making cutouts thorugh 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 Handling of debris is more efficient as bulk of concrete is removed as units	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 The greater the percentage of steel reinforcement contained within 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

(Continued)

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Table 2 (Continued)

Category	Method	Features	Considerations
Cutting (Continued)	Stitch drilling (Continued)		Uncut portions between adjacent boreholes will prevent removal Concrete toughness for percussion drilling and aggregate hardness for diamond coring will affect cutting rate and cost Personnel must wear hearing protection due to 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 an effective means of cutting prestressed members Irregular shapes can be cut Minimal vibration and dust produced Handling of debris is more efficient as bulk of concrete is removed as units	Method is of limited availability commercially and is costly Method cannot be used in areas where flammable or combustible materials exist Remaining concrete has thermal damage with more extensive damage occurring around steel reinforcement Noise, smoke, and fumes are produced Personnel must be protected from heat and hot fly rock produced by cutting operation Additional safety precautions are required due to the hazards associated with the storge, handling, and use of compressed and flammable gases
Impacting	Mechanical impacting, boom-mounted breaker	Method is 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 Boom allows concrete to be removed from vertical and overhead members Boom-mounted breakers are widely available commercially Method produces easily handled debris	The blow energy delivered to the concrete should be limited to protect the structure being repaired and surrounding structures from damage due to the high cyclic energy generated Performance is function of concrete soundness and toughness Productivity is significantly reduced when boom is operated from top of wall as operator's view of removal is very limited Care must be taken to avoid damage to supporting members Concrete that remains is damaged (microcracking) along with reinforcing steel Sawcuts at boundaries should be employed to reduce the occurrence of feathered edges Dust is produced (Continued)

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Table 2 (Continued)

Category	Method	Features	Considerations
Impacting (Continued)	Mechanical impacting, boom-mounted breaker (Continued)		Personnel must wear hearing protection due to the high levels of noise produced
	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 widely available commercially Breakers can be operated by unskilled labor Method produces relatively small debris that is easily handled	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 Significant loss in productivity occurs when breaking action is other than downward Removal boundaries will likely require 25 mm (1 in.) deep or greater sawcut to reduce the occurrence of feathered edges 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 due to 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 For decks, hammer can completely punch thorugh slab with each blow leaving only the reinforcing steel Method produces easily handled debris	Method is more applicable for total demolition of a concrete member rather 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 due to the high cyclic energy generated Care must be taken to avoid damage to supporting members Performance is function of concrete soundness and toughness Concrete that remains is damaged (microcracking) along with reinforcing steel Sawcuts at boundaries should be employed to reduce the occurrence of feathered edges (Continued)

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Table 2 (Continued)

Category	Method	Features	Considerations
Milling	Hydromilling (also known as hydrodemolation 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 does not damage the concrete that remains Steel reinforcing is left undamaged for reuse Method produces easily handled, aggregate-size debris	Method is costly Productivity is significantly reduced when sound concrete is being removed Removal profile will vary with changes in depth of deterioration Holes thorugh member (blow-outs) are a common occurrence when removal is near full depth of member Repair of blow-outs require 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 (l,000 gal/hr)) Laitence coating that is deposited on remaining surfaces during removal should be washed from surface before coating dries Flow of wastewater may have to be controlled An environmental impact statement will be required if wastewater is to enter a waterway Personnel must wear hearing protection due to high level of noise produced Fly rock is produced Additional safety requirements are required due to the high pressures (100 to 300 MPa (16,000 to 40,000 psi) range) produced by the system
	Rotary head milling	Method is applicable for removing deteriorated concrete from mass structures 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	Removal is limited to concrete outside structural steel reinforcement Significant loss of productivity occurs in sound concrete Productivity is significanlty reduced when boom is operated from top of wall as operator's view of cutting is very limited Concrete that remains will likely be damaged (microcracking) (Continued)

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Table 2 (Continued)

Category	Method	Features	Considerations
Milling (Continued	Rotary head milling (Continued)	Boom allows removal from vertical and overhead surfaces Concrete containing wire mesh can be cut without significant losses in productivity Method produces relatively small debris that is easily handled	Skid loader units typically mill a more uniform removal profile than other rotary head and water jet units Noise, vibration, and dust are produced
Presplitting	Chemical presplitting, expansive agents	Method is applicable for presplitting concrete members where depth of boreholes is 10 times borehole diameter or greater Expansive products can be used to produce vertical presplitting planes of significant depth Some products form a clay type of material when mixed with water that allows the material to be packed into horizontal holes No vibration, noise, or fly rock is produced other than that produced by the drilling of boreholes and the secondary breakage method	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 that are prills or become slurries when water is added are best used in gravity filled, vertical, or near vertical holes Products are limited to a specific temperature range A rotary head milling or mechanical impacting method will be required to complete removal 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 Splitter can be reinserted into boreholes to continue removal for full depth of holes	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 Development of presplitting plane is significantly decreased by presence of reinforcing steel normal to presplit plane (Continued)

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Table 8 (Continued)

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