

Removal and Reuse of Hardened Concrete

Reported by ACI Committee 555

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This report presents information on removal and reuse of hardened concrete. Guidance for assessment of concrete structures for complete or partial demolition is provided. The applicability, advantages, limitations, and safety considerations of various types of concrete removal methods, including hand tools, hand-operated power tools, vehicle-mounted equipment, explosive blasting, drills and saws, nonexplosive demolition agents, mechanical splitters, heating and thermal tools, and hydrodemolition (water-jet blasting), are provided. The available surface removal systems, their probable applications, and advantages and disadvantages of various types of surface removal systems are discussed. Considerations for evaluating and processing waste concrete for production of aggregates suitable for reuses in concrete construction are presented.

Keywords: aggregates; concrete removal; condition survey; demolition; diamond saw; drop hammer; explosive blasting; hardened concrete; hydro-demolition; impact breaker; jet-flame cutter; mechanical splitter; mixture proportion; nonexplosive demolition agent; recycled aggregates; recycled concrete; rotating cutter head; spring-action breaker; thermal lance; water-jet blasting; wrecking ball.

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CHAPTER 1—INTRODUCTION

1.1—Scope

This report provides available information on concrete removal methods with detailed discussions on surface removal. Reuse of removed concrete as concrete aggregate is also addressed. The type and kind of concrete and its location within a structure directly affect the removal methods to be used. Selection of proper tools and equipment are critical for a cost-effective and safe concrete removal project.

1.2—Objective

Driven by cost, need, and limited resources, the technology for concrete removal and reuse is rapidly advancing. Partial removal of critical structural components for repair rather than replacement, geographical constraints, access to structures planned for removal, environmental regulations, and worker and structure safety will continue to effect an evolution of developing methods and equipment.

With safety as a foremost consideration, thorough planning is essential when engaged in a removal project. The scope and type of concrete to be removed should be evaluated and examined in detail to determine the most advantageous system(s). This report provides information on selecting the most appropriate systems.

Concrete reuse is primarily related to a project's location. For example, limited availability of materials in a particular region may result in a cost-effective use of equipment and manpower to remove nearby concrete structures with the intent of reusing the removed materials as a roadway base or as coarse aggregate for concrete. This report is confined to the evaluation and processing of hardened concrete used as concrete coarse aggregates.

Work continues in a number of countries to improve equipment and methods, including the use of robotics. Proceedings from the RILEM Symposium held in October 1993 in Odense, Denmark, and other RILEM publications provide additional information. These publications include: *Demolition and Reuse of Concrete and Masonry* (Kasai 1988), *Demolition and Reuse of Concrete and Masonry* (Lauritzen 1993), "Disaster Planning, Structural Assessment, Demolition and Recycling" (De Pauw and Lauritzen 1993), "Recycling of Demolished Concrete and Masonry" (Hansen 1992), and "Specification for Concrete With Recycled Aggregates" (RILEM Technical Committee 121 1993). The Strategic Highway Research Program (SHRP) in the United States studied problems that have an influence on the removal of concrete for bridges (Vorster et al. 1992).

CHAPTER 2—KINDS OF CONCRETE AND DEGREE OF REMOVAL

2.1—Introduction

This chapter addresses complete and partial removal from different types of structures and assessment of structure considering safety, stability, cost, constructibility, and environmental impact. The complete or partial removal of prestressed, reinforced, and unreinforced concrete structures should be assessed by a competent team experienced in all phases of the concrete removal operation.

One should identify sound concrete and examine what effect the removal may have on remaining concrete and reinforcement when partial removal is undertaken. Most importantly, concrete removal or demolition should be performed under appropriate supervision, regardless of the project size.

2.2—Assessment of concrete structures for complete or partial demolition

2.2.1 General considerations—Guidance on performing a condition survey of concrete structures is covered extensively in ACI 201.1R. Listed below are other general items to consider before either partial or complete concrete removal. If the decision to remove concrete is based on economic or reasons other than concrete deterioration, a detailed condition survey might not be necessary.

2.2.1.1 Safety—A predemolition survey should be performed to determine if the planned work could cause any structure to collapse. Before starting work, a survey of the job site should be made to determine the hazards and the safeguards necessary to ensure that work is performed safely. Continually check for hazards due to weakening of the structure.

2.2.1.2 Environmental impact—A work plan requiring the removal of a structure, either partially or totally, should address the impact on the surrounding environment. Impacts on the environment include: neighboring tenants and surrounding structures; noise pollution; dust pollution; water runoffs due to work, storms, or both; and other environmental factors such as asbestos and hazardous chemicals. An inventory of potential environmental impacts should be developed and used as a checklist during concrete removal operations.

2.2.1.3 Plans provided or drawn for assessment documentation—During the condition survey of the concrete structure, prepare drawings or sketches that reflect existing conditions. These drawings or sketches become part of the condition survey report to provide preremoval documentation.

2.2.1.4 Complete set of structural and architectural drawings—In performing a condition survey of concrete structures, the use of as-built structural and architectural drawings is strongly recommended for work plan development. The drawings can be reviewed and evaluated for assessing existing conditions, areas of distress or potential hazards, development of work plans, and concrete removal operations. With accurate and thorough drawings, a work plan can be developed safely and effectively, while minimizing environmental impacts and costly errors. If original drawings are not available or if modifications appear to have been made, spot de-

structive exploration may need to be done to ascertain reinforcement location, size, and condition.

2.2.1.5 Budgetary and logistic constraints—Budgetary and logistic constraints should be identified and incorporated into the work plan.

2.2.2 Evaluation of concrete

2.2.2.1 Field documentation (visual examination)—Refer to ACI 201.1R to develop a checklist for field documentation of the structure. ACI 201.1R provides information on examination of uniformity and rating of distress manifestations.

2.2.2.2 Detailed examination

(i) *Petrography*—The usefulness of any petrographic examination procedure on the objectives of the investigation, proposed or underway, can be determined by a discussion with an experienced petrographer. ASTM C 457 can be used to develop data that will explain why freezing-and-thawing-related damage has occurred. ASTM C 856 gives the following purposes for petrographic examination of concrete:

- Determine, in detail, the condition of concrete in a structure;
- Determine inferior quality, distress, or deterioration of concrete in a structure;
- Determine whether alkali-silica or alkali-carbonate reaction, or cement-aggregate reaction, or reactions between contaminants and the matrix have taken place, and their effects upon the concrete;
- Determine whether the concrete has been subjected to and affected by sulfate attack, other chemical attack, early freezing, or to other harmful effects of freezing and thawing; and
- Determine whether concrete subjected to fire is essentially undamaged or moderately or seriously damaged.

(ii) *Nondestructive testing (NDT)*—There are numerous nondestructive test methods for estimating strength of concrete, a few of which are listed as follows:

- a) Surface hardness methods;
- b) Penetration resistance techniques;
- c) Pullout tests; and
- d) Ultrasonic pulse velocity method.

There are also other nondestructive test methods for determining properties other than strength: a few are listed as follows:

- a) Magnetic methods—reinforcement cover and location;
- b) Electrical methods—reinforcement corrosion, thickness of concrete pavements, moisture content, and moisture penetration;
- c) Radioactive methods—density, voids, composition, and segregation; and
- d) Ultrasonic pulse velocity and pulse echo techniques—to determine cracks and voids in mass concrete.

For additional test methods and their application and limitations, refer to ACI 228.1R and ACI SP-82 (Malhotra 1984).

2.2.2.3 Cause of distress—In developing removal procedures, consider the cause of distress on the removal process as it may affect the structure's integrity.

2.2.2.4 Reuse of concrete rubble—Refer to [Chapter 5](#).

2.2.2.5 Transport and deposit of waste material—Very little of the approximately 135 million tons (123 million

tonnes) of removed concrete rubble in European communities, United States, and Japan is reused. Due to the declining availability of disposal sites, recycling alternatives should be evaluated as quality aggregate sources.

2.2.3 Report

2.2.3.1 Summary of scope of work—Define purpose and limitations of preliminary investigation and findings, concrete removal work plan, safety, schedule requirements, environmental aspects, or recycling plan.

2.2.3.2 Findings—Describe the structure, its present condition, nature of loading and detrimental elements, original condition of the structure, materials used in construction, and practices used in constructing the structure. Photographs should be used to illustrate the conditions.

2.2.3.3 Recommendations—Include complete or partial demolition, salvage, removal methods, safety and environmental considerations, and further investigation or testing as required.

2.2.3.4 Total estimated cost—Provide cost estimates for various removal methods, partial or complete concrete removal, reuse, transportation and waste disposal, and additional inspection and testing. Other associated costs should be identified and estimated where practical, including protection of adjacent construction.

2.2.3.5 Photos and drawings—Use of drawings illustrating as-built, current conditions and areas of concern (for example, concrete quality, distress, loading, and utilities) is required to demonstrate the need for concrete removal, the logic for the method, and amount of removal recommended. Photographs can illustrate distress manifestations and provide documentation of existing conditions. Where possible, include some means for identifying scale, such as including a ruler or other recognized object like a pencil or coin.

2.2.3.6 Supporting data in comprehensive form—To support findings and recommendations, the data developed through visual examination, coring, nondestructive testing, petrography, photographs, drawings, and sketches should be arranged in a comprehensive format that can readily be followed. For example, plans could be labeled with symbols identifying where samples or photos were taken, with each sample or photo containing a brief but concise description. It is essential that the extent of damage be established, regardless of the cause. Whether concrete quality of the remaining structure is sufficient to support a sound repair should be determined.

2.2.4 Engineering survey—Before starting any demolition operations, an engineering survey of the structure conducted by a competent individual is required. The purpose of the survey is to determine the condition of the structure so that precautionary measures can be taken, if necessary, to prevent premature collapse or failure of any portion of the structure.

2.2.5 Health and safety safeguards—A number of steps should be taken to safeguard the health and safety of workers at the job site. These preparatory operations involve the overall planning of the demolition job, including the methods used to demolish the structure, the necessary equipment, and the measures to perform the work safely. Having a demolition is as important as actually doing the work.

2.3—Types and degree of removal

2.3.1 Purpose of removal

2.3.1.1 Material conditions—Concrete removal from a structure may be required due to structure distress where the integrity of the concrete has deteriorated, or where upgrading or modification of a structure where sound concrete needs to be removed for an addition. In some instances where concrete removal is necessary due to distress, sound concrete may need to be removed for anchoring purposes.

2.3.1.2 Complete demolition (one-piece, multiple-piece, rubble, crushed)—Several methods and various types of equipment can be used in concrete removal. Depending on the size, complexity, available equipment, and safety aspects, concrete elements can be removed as single or multiple pieces for disposal, or crushed and reduced to rubble for general disposal or recycling.

2.3.1.3 Partial removal—In partial demolition of concrete structures, salvaging or utilizing the remaining, intact structure should be properly evaluated.

- Replace what is removed—a portion of a structure should be removed and replaced in kind with proper adjustments to the added element to prevent any previous distress.
- Do not replace what is removed—a section of a concrete element is removed and is not critical to the overall integrity of the remaining structure. An example would be removal of architectural or redundant elements that are not essential to the structural integrity.
- Create opening or void—partial demolition may be required to provide temporary or permanent access for equipment, fixtures, framing, or other purposes. The structure is thoroughly evaluated to determine whether partial demolition can be performed with or without temporary or permanent external supports.

With diminishing numbers of disposal sites, waste management has become widespread. In the development of a work plan for concrete removal, the recycling of the concrete waste—for example, reinforcing steel, aggregates, and concrete—will need to be evaluated for practicality and economics. Creative reuse of concrete can be challenging and rewarding. Refer to [Chapter 5](#) of this report for reuse of hardened concrete in the production of ready-mix concrete.

2.3.2 Degrees of removal

- Complete demolition
- Partial demolition may be performed to correct an alignment defect or other deficiency in new construction or remove deteriorated concrete in an existing structure.
 - i. Layer (overlay, cover, finish)—a partial demolition layer usually involves removal to a certain depth greater than 1/2 in. (13 mm)
 - (1) Physically defined limit (different mixtures, barrier, material integrity)
 - (2) Arbitrary limit (specific depth)
 - ii. Surface—a surface demolition usually is a surface removal of less than 1/2 in. (13 mm)
 - (1) Binder and fines only
 - (2) All constituents
- Piece of section

i. Entire element

ii. Portion of element

- (1) Physically defined limit (joint, different mixtures, barrier, material integrity)
- (2) Arbitrary limit (specified size)
- (3) Reinforcement

2.4—Types of concrete and effects on removal and reuse

2.4.1 General—Concrete structures can be classified generally into four groups: mass concrete structures; underground structures; reinforced concrete structures; and prestressed/post-tensioned structures. With the numerous demolition techniques available, such as crushing, chopping, splitting, blasting, cutting/drilling, laser, electric heating, and microwaving, selecting the appropriate method is important. When selecting a removal method the following considerations should be evaluated:

- Safety;
- Finance;
- Time limits;
- Quality of concrete and geometry of the demolished object;
- Quantities, location, and a breaking boundary;
- Aggregate hardness;
- Concrete compressive strength;
- Environment;
- Specific risks;
- Utility locations; and
- Adjoining construction.

2.4.2 Mass concrete structures—Mass concrete structures include hydraulic structures, dams, large mat foundations, bridge piers, thick walls, and reactor foundations. Typical concrete removal methods used are explosive blasting, diamond wire sawing, presplitting using nonexplosive demolition agents and mechanical splitters, vehicle-mounted impact hammering and rotary head cutting, stitch cutting, and drilling. Methods less used but available include remote-controlled thermal lance cutting, abrasive water-jet blasting, electrical heating of steel reinforcement, and microwave heating of cover concrete.

2.4.3 Underground structures—Removal of underground structures is more difficult, requiring the need for horizontal support and individuals experienced in both planning and supervising the removal. Underground structures may be removed using hydraulic breakers, large hammers, blasting, crushing augers, diamond wire saws, and chemical splitting.

2.4.4 Reinforced concrete structures—Most of the methods discussed in [Chapter 3](#) are applicable to reinforced concrete structures depending on the type, size, use, and degree of removal.

2.4.5 Prestressed/post-tensioned structures—Prestressed/post-tensioned concrete structural elements may be removed using thermal lance, hydraulic breaker, drop ball, and jackhammer. Particular care should be taken in demolition as the stored energy in the tendons can, if released suddenly, cause structural collapse or whiplash of tendons. Occupational Safety and Health Administration (Occupational Safety and Health Administration) components (Occupational Safety and Health Administration)

tion 1991b). Never allow workers to be near anchorages during any form of removal other than controlled detensioning.

The *OSHA Technical Manual* (Occupational Safety and Health Administration 1991b) identifies four main categories of prestressed members. The category, or categories, should be identified before attempting any demolition, bearing in mind that any prestressed structure may contain elements of more than one category.

- **Category 1**—Members prestressed before the application of the superimposed loads and having all tendons fully bonded to the concrete or grouted within ducts.
- **Category 2**—As Category 1, but with the tendons left ungrouted. This type of construction can sometimes be recognized from the access points that may have been provided for inspection of the cables and anchors. Unbonded tendons have been used in the construction of beams, slabs, and other members. These tendons are protected by grease and may be surrounded by plastic sheathing instead of the usual metal duct.
- **Category 3**—Members that are prestressed progressively as the building construction proceeds and the dead load increases, using bonded tendons, as Category 1.
- **Category 4**—As Category 3, but using unbonded tendons as Category 2.

Examples of construction using members of Categories 3 and 4 may be found, for example, in the podium of a tall building or some types of bridges. They require that particular care be taken in demolition (Occupational Safety and Health Administration 1991b).

2.4.5.1 Pretensioned member—Simple pretensioned beams and slabs of spans up to about 23 ft (7 m) have been demolished in a manner similar to ordinary reinforced concrete. Pretensioned beams and slabs may be lifted and lowered to the ground as complete units after the removal of any composite concrete covering from tops and ends of the units. If units are too large to be removed in one section, a plan that may involve temporary support should be developed by a professional engineer experienced in prestressed concrete removal.

2.4.5.2 Separately stressed precast units—If possible, units of this type should be lowered to the ground before breaking up, if possible. Requirements dictated by an experienced engineer should be adhered to closely, especially where there are ungrouted tendons.

2.4.5.3 Monolithic structures—A professional engineer experienced in prestressed concrete construction should be consulted before any attempt is made to expose the tendons or anchorages of structures where two or more members have been stressed together. Temporary supports are usually required so the tendons and the anchorage can be cautiously exposed. In these circumstances, it is essential that indiscriminate attempts to expose and destress the tendons and anchorages are not made.

2.4.5.4 Progressively prestressed structures—The advice of a professional engineer is required for removal of progressively prestressed structures. The engineer's recommended removal methods should be strictly adhered to. The stored energy in this type of structure is large.

2.5—Monitoring and safety considerations

2.5.1 Methods to monitor the demolition—Because each method of removal is different, a separate analysis should be prepared for each method. Outlined as follows is a general guideline to assist in developing a safety program. Each job will need to be evaluated individually and coordinated with affected governmental agencies. The following provisions are not all-inclusive.

2.5.1.1 Planning for construction—Each operation and stage of a project should be planned in advance, beginning before the preparation of bids and then throughout the project. Superintendents and foremen should participate in this planning process. Thorough planning will provide a well-organized job, eliminating the potential for some accidents. The following items should be considered during planning.

- Location of utilities and services:
 - a. Review locations of all utilities. Whenever operations are required to be within the minimum distances of power lines established in the OSHA regulation (Occupational Safety and Health Administration 1991a), arrangements should be made to have the line moved or de-energized, erect barriers, or set up special working procedures. Except on private easements, the appropriate regional notification center should be contacted to determine the location of subsurface utility installations in the area before excavation; and
 - b. Locate equipment, tool sheds, and office in a safe and convenient place.
- Employee access problems should be resolved by the individual in charge at the project:
 - a. Adequate work areas;
 - b. Adequate walkways and runways;
 - c. Adequate ladders, stairway, or elevators;
 - d. Work areas and passageways clear of rubbish, debris, and nails;
 - e. Protection of floor and roof openings; and
 - f. Adequate illumination.
- Schedule work for safety:
 - a. Have safety equipment (hard hats, goggles, ear plugs, trench jacks, safety belts, and respiratory protection) on site when needed;
 - b. Plan work so that there are not too many trades in a small area at the same time; and
 - c. Schedule work crews so the flow of equipment and manpower does not create a safety hazard.
- Work procedure:
 - a. Material handling—
 - 1) Plan for methods of elevating, lowering, and handling materials (adequate space, proper auxiliary equipment, such as cranes, hoists, elevators, and trucks); and
 - 2) Plan for methods of loading and unloading (adequate space, proper auxiliary equipment, such as loaders, cranes, rigging, and forklifts).
 - b. Plan for the use of tools and equipment—
 - 1) Repair, maintenance, and care;
 - 2) Inspection; and

3) Adequate supplies of the right tools for each part of the job.

2.5.1.2 General safety precautions—The following are general safety precautions:

- Every reasonable effort should be taken to ensure the safety of workers in all situations, whether or not provided for in a company's rules and safety program;
- No worker should be required or knowingly permitted to work in an unsafe place, unless for the purpose of making it safe, and then only after proper precautions have been taken to protect the worker doing such work;
- Before the start of work, the supervisor or safety officer, or both, should survey site conditions for risks or hazards and determine safeguards necessary to accomplish the work in a safe manner;
- A training program should be designed and implemented during the project that will instruct workers in general safe work practices as well as methods to avoid the unique hazards of the workers' specific job assignments;
- Periodic inspections should be conducted during the project to identify unsafe conditions and work practices. Those unsafe conditions and work practices should be corrected immediately; and
- All required safety and health notices should be posted at the job site, as required, or be otherwise available at the site.

2.5.1.3 Safety program objectives—The following are safety program objectives:

- To provide a safety and health program consistent with good construction demolition practices;
- To prevent accidents, injuries, and illnesses;
- To create an attitude of safety consciousness among general management, field supervision, and all crafts;
- To assign specific responsibilities for effective implementation and continuation of the safety program; and
- To provide continued development of safety and health education, training and testing.

2.5.1.4 Safety program implementation—The following can help implement a safety program:

- Planning for safety in the concrete removal operation through job hazard analysis. Draw upon available or hired experience and expertise to anticipate and eliminate accident-prone conditions;
- Providing mechanical and physical safeguards to the maximum extent possible;
- Conducting a program of routine safety and health inspections to identify and correct unsafe working conditions or practices, control health hazards, and comply fully with the safety and health standards for every job;
- Training all individuals in proper safety and health practices;
- Providing necessary personal protective equipment and instructions for its proper use and care;
- Providing a means for employees to inform their supervisors of hazards at the work site;
- Investigating, promptly and thoroughly, every accident to determine the cause and correct the problem to pre-

vent its recurrence; and

- Providing first-aid materials and trained first-aid personnel on job sites.

2.5.1.5 Safety program requirements—The following are requirements for a safety program:

- Develop and implement a safety program with rules and assigned responsibilities;
- Make these rules and policies known to all employees and subcontractors;
- Appoint a safety coordinator;
- Establish a safety training program to ensure that employees are trained in basic hazards of the job site and specific hazards unique to each employee's job assignment;
- Provide superintendents with appropriate safety rules and regulations from government agencies;
- Discipline employees who willfully disregard this program; and
- Reward employees for good safety performance.

CHAPTER 3—REMOVAL METHODS

3.1—Introduction

During the 1950s and 1960s, the contractor generally was limited to hand-held breakers and jackhammers operated by compressed air, core drills, walk-behind diamond saws, wrecking balls, small hydraulic hammers, and contractor-built drop hammers for breaking up concrete. A few specialty demolition contractors removed whole structures.

Today, this has all changed. Equipment and methods developed in one country are soon marketed worldwide and advertised in the various trade magazines. Trade associations provide a good source of firms performing a particular type of work, and contractors keep extensive lists of subcontractors that do work in particular cities. Equipment dealers, demolition contractors, concrete sawing and drilling contractors, and a wide range of construction magazines are helpful to stay abreast of equipment that is available for concrete removal. Due to the high cost, operator training, and skilled supervision required, many items of equipment and methods will be provided by specialty contractors (Peurifoy and Ledbetter 1985).

This chapter provides general description and summary information on concrete removal systems and methods. The advantages and limitations of various concrete removal methods can be found in ACI 546R.

3.2—Hand tools

A number of hand tools used in stone and masonry work for many years are good for removing concrete in small amounts. Pry bars, bush hammers, sledgehammers, drills, points and various chisels are just a few of these tools. Reshaping and hardening of the bits is needed.

3.3—Hand-operated power tools

3.3.1 Hand-held pneumatic tools—Hand-held pneumatic tools are available in a wide range of sizes (pavement breakers and jackhammers being the most common). These types of tools have been in use for almost 100 years and are of rug-



Fig. 3.1—Drop blade (highway pavement demolition).

ged construction. Compressed air is usually available on most construction sites. Lighter chipping hammers are also available. It is necessary to ensure an adequate supply of air pressure and volume as well as provisions for moisture collection and lubrication (Manning 1991).

3.3.2 Hand-held hydraulic tools—Hydraulic power is provided by small, lightweight power packs that can also operate a number of other tools. The Hydraulic Tool Manufacturer's Association (HTMA) classifies hydraulic tools as Type I, II, or III with minimum flow rates of 5, 8, and 12 gpm (19, 30, and 45 lpm), respectively. A wide range of tools is available, including small impact hammers, drills, saws, and grinders for use in concrete removal.

3.3.3 Hand-held electrical tools—Hand-held electrical tools are the smallest type of hand-held power tools available, have lower energy output, and are usually limited to use in confined areas.

3.3.4 Gasoline-powered tools—Gasoline-powered tools are ideal for small drilling and breaking jobs in hard-to-reach locations. These tools are available in two models, one for drilling and percussion, the other with percussion only. Both tools weigh less than 60 lb (27 kg) with a number of drill steels and other tool bits available.

3.3.5 Drop hammers/blades—Drop hammers/blades are used to demolish concrete highway pavements, parking lots, and other slabs on grade (Fig. 3.1). Weight and drop height are balanced to thickness and strength of concrete and degree of breakage required. Several firms manufacture small three-wheeled hydraulic powered, self-contained drop hammer concrete breakers that are operated by one person. They are available in several sizes. These units are faster than hand-operated pavement breakers and are available with several engine options and an assortment of tool bits. They are faster than a jackhammer or 90 lb (41 kg) pavement breaker. They produce very little dust. They only require one operator and the units are self-propelled and easily portable. The units are ideal for removing small areas of slab on grade up to 12 in. (300 mm) thick. Depending on the model, units are available with a breaking force up to 3800 ft-lb (5150 N-m).



Fig. 3.2—Vehicle-mounted impact breaker (bridge deck demolition).

3.4—Vehicle-mounted equipment

Demolition attachments of a wide range of sizes and types are available to mount on small backhoes, skid loaders, and equipment requiring carriers of over 200,000 lb (90,000 kg) in weight. A wrecking ball requires a crane boom. Other demolition attachments need to have a carrier equipped as a backhoe or excavator.

The vehicles can be rubber tired or crawler mounted. The unit should have sufficient hydraulic capacity to operate both the boom and the attachment. Small units have been raised with large cranes to upper levels of buildings. Where used on elevated slabs, care needs to be taken not to overload the slab or to remove structural supports holding up the slab supporting the equipment during demolition.

3.4.1 Hydraulic/pneumatic impact breakers/hammers—Hydraulic/pneumatic impact breakers/hammers (Fig. 3.2) are common pieces of equipment available from many manufacturers. Several manufacturers market several different sizes with impact energy classes from 125 ft-lb (169 J) to over 20,000 ft-lb (27,000 J).

The hammer selected should be matched to the carrier it will be mounted on, and the frequency or impact rate, hydraulic pressure, working weight, and design details need to be considered when selecting a hammer. Some specifications limit the impact energy where only partial removal of an existing structure is required. Advantages of the impact hammers are the wide range of sizes and the ready availability. These units have essentially replaced the wrecking ball.

Pneumatic breakers are available in fewer sizes and by fewer manufacturers. The breakers, powered by compressed air, can be used where the carrier does not have sufficient hydraulic capability. Both pneumatic and hydraulic breakers can be used for underwater work.

3.4.2 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. 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 the energy is released just prior to impact. There are truck units



Fig. 3.3—Spring-action breaker (bridge deck demolition).



Fig. 3.4—Twin-drum rotary cutter head.

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. Spring-action hammers (Fig. 3.3) are available in several sizes with blow energies up to 300,000 ft.-lb. (400 kJ) (Manning 1991). This equipment is much faster than the impact hammers where the thickness of the concrete pavement permits its use. When the equipment is truck-mounted on rubber tires, it can be easily moved from job site to job site.

3.4.3 Wrecking ball and crane—The wrecking ball is attached to a crane and is either dropped or swung into the concrete. The weight of the ball can vary depending on the crane capacity. This method requires a highly skilled operator for safe operation. The recommendations for wrecking ball versus crane capacity, safety factors, breaking strength of supporting live load, and other safety considerations can be found in the National Cooperative Highway Research Program Synthesis of Highway Practice 169 (Manning 1991).

3.4.4 Rotating cutter heads—Rotating cutter head attachments provide continuous cutting by the rotation of the cutter drum(s) with sizes that fit various hydraulic excavators and skid loaders. Two styles of cutter heads are available for excavators: (1) transverse, twin drums (Fig. 3.4); and (2) in-line,



Fig. 3.5—Single-drum rotary cutter head (planer).

single drum. The drum for the in-line cutter head rotates around the axis of the boom and works similar to a large drill. The drums are available with flat or rotating conical bits.

Skid loaders are used to remove concrete from top faces of decks, slabs, and lock walls, whereas excavators are typically used to remove concrete from vertical and overhead faces. Skid loaders use a single transverse drum attachment (Fig. 3.5).

3.4.5 Concrete crushers—Concrete crushers, in a number of sizes and cutting jaw configurations, are ideal for removing curbs, parapets, slabs, and beam and wall sections, and for crushing large pieces of concrete removed by other methods. Models are available with one hydraulic cylinder, others with two cylinders, and a wide range of sizes, from small units with only a few tons, to large ones with 2500 tons (22,000 kN) of crushing power.

3.4.6 Ripper—The ripper is a large blade attached to a backhoe used to break up slabs-on-grade and to separate the reinforcing steel from the concrete. Ripper blades have also been mounted on large crawler tractors to remove reinforcing steel after the concrete is broken up by other methods. The ripper is ideal for removing large areas of slab-on-grade and concrete pavement.

3.4.7 Resonant frequency breaker—The resonant frequency breaker fractures or breaks concrete highway pavement using a self-propelled, four-wheel rubber-tired power unit that uses resonant beam technology to apply energy through a high-frequency resonant impact breaker to the concrete pavement (Fig. 3.6). The unit has been used successfully on interstate highway work with normal breaking rates averaging 10,000 yd²/day (8400 m²/day).

3.5—Explosive blasting

Explosive blasting has been successfully used for removal of large volumes of distressed and deteriorated concrete by the Corps of Engineers on a number of locks and dams (Fig. 3.7). Blasting has been used for complete building demolition and for underwater demolition (Kasai 1988).

Concrete is a difficult material to blast because of the variation in strength and amount of reinforcing steel present (Hemphill 1981). Safety regulations, environmental consid-