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CONCRETE RECYCLING ALTERNATIVES FOR MILITARY INSTALLATIONS

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CONCRETE RECYCLING ALTERNATIVES FOR MILITARY INSTALLATIONS

1. Purpose

a. This Public Works Technical Bulleting (PWTB) provides guidance for the use of recycled concrete at Army installations in the continental United States (CONUS).

b. All PWTBs are available electronically at the National Institute of Building Sciences' Whole Building Design Guide webpage, which is accessible through this link:

http://www.wbdg.org/ccb/browse_cat.php?o=31&c=215

2. Applicability

This PWTB applies to all US Army Corps of Engineers (USACE) Districts and Department of the Army CONUS installation personnel that are responsible for generating or managing concrete materials from construction projects, or those who specify, purchase, and utilize aggregate products.

3. References

a. Army Regulation (AR) 200-1, "Environmental Protection and Enhancement," Chapter 10, "Waste Management," Section 2, "Solid waste," 13 December 2007.

b. AR 420-1, "Army Facilities Management," 12 February 2008.

c. Memorandum, Office of the Assistant Chief of Staff for Installation Management (OACSIM), "Sustainable Management of Waste in Military Construction, Renovation and Demolition Activities" February 2006, revised 11 July 2006.

d. White Paper, “Army Vision for Net Zero.” Assistant Secretary of the Army Installations, Energy and Environment (ASA {IE&E]), Katherine Hammack, 10 October 2010.

e. Executive Order (EO) 13514 “Federal Leadership in Environmental, Energy, and Economic Performance,” *Federal Register*, 8 October 2009.

4. Discussion

a. AR 200-1 (Chapter 10-2) requires the Army to minimize solid waste generation and disposal, and then maximize recovery, recycling, and reuse through pollution prevention actions.

b. AR 420-1 addresses Army policies regarding solid waste management including construction and demolition waste.

c. Construction and demolition (C&D) waste is a major contributor to the solid waste burden at Army installations, with concrete being the largest portion of C&D waste. Therefore, Army policies are in place for the reduction of C&D materials in the waste stream. The Army policy titled “Sustainable Management of Waste in Military Construction, Renovation and Demolition Activities” requires a minimum of 50% C&D diversion (by weight) for Facilities Reduction Program (FRP) and other projects.

d. The Net Zero program is a relatively new initiative to address the efficient use of energy, water, and waste throughout the Army. This program defines a Net Zero Waste Installation as an installation that reduces, reuses, and recovers waste streams, converting them to resource values with zero landfill over the course of a year.

e. In addition to Army mandates, EO 13514 directs federal agencies to promote pollution prevention and eliminate waste by diverting at least 50% of C&D waste by the end of fiscal year (FY) 2015.

f. Concrete recycling presents an environmentally friendly alternative, because it conserves virgin resources and increases the waste diversion required by Army policy to reach the Net

Zero Waste goal. Potential uses for recycled concrete include aggregate base course for pavements, road base, foundations, parking lots, drainage layers, and many other uses that are currently being tested. Army installations such as Fort Campbell, Fort Hood, and Fort Jackson have been able to successfully recycle concrete for various applications throughout each site.

g. Appendix A provides an overview of concrete recycling and reuse, including why both of these actions are important to the Army. This appendix also covers background on sustainability and waste reduction efforts by the Army including the Net Zero Installation Strategy. In addition, this appendix discusses different facts regarding concrete recycling, such as the actual process of crushing the concrete and the necessary equipment. Also discussed are the industry standards that apply to the potential uses for the crushed concrete and its properties when compared to virgin materials.

h. Appendix B presents different options for reusing crushed concrete in military installations. Logistical and regulatory limitations in installation environments can be seen as limiting the potential uses. Thus after collecting experiences from different installations, state departments of transportation over the country, and innovative research, this appendix presents projects that are less complex to execute from a logistics point of view. Those projects include trails, fire breaks, parking lots, pipe bedding, soil stabilization, landscaping, and other innovative uses that are introduced, too.

i. Appendix C summarizes important points to consider if conducting a concrete crushing operation on post. The information in this appendix was collected by interviewing several solid waste managers at different installations. Their lessons learned and perspective can serve as guidance for future projects and as a starting point for installations that still have not tried reusing crushed concrete on site.

j. Appendix D lists the references used to prepare this document.

k. Appendix E lists abbreviations used in this PWTB. It also includes a chart that may be used to convert the inch-pound measurements to the International System (SI) of measurements.

5. Points of Contact

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FOR THE COMMANDER:

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APPENDIX A:

CONCRETE RECYCLING AND REUSE AS AN ALTERNATIVE FOR C&D WASTE REDUCTION

Background of Construction and Demolition Waste

Construction and demolition (C&D) waste is a major contributor to Army installations' solid waste burden. C&D waste is typically composed of the following materials:

- asphalt
- bricks
- carpet and carpet pad
- corrugated cardboard
- clean dimensional wood
- concrete and rock
- concrete masonry units (CMU)
- dirt
- doors
- ferrous & nonferrous metals such as banding, stud trim, ductwork, piping, rebar, roofing, other trim, steel, iron, galvanized sheet steel, stainless steel, aluminum, copper, zinc, lead, brass, and bronze.
- fluorescent lights and ballasts
- gypsum wall board (drywall)
- land-clearing debris or green materials (e.g., tree trimmings)
- paint
- plastic wrap, buckets, PVC
- roofing shingles
- used beverage containers
- wood

Due to its large volume and weight, concrete is a main component of the C&D waste. Concrete, usually reinforced with steel, is generated in large quantities by demolition projects, thus providing opportunities to reuse and recycle these materials. Some Army installations report that C&D constitutes 80% of their solid waste stream; about 63% of this waste stream is estimated to be concrete materials (Cosper 2004).

Diversion Efforts

The federal government and the Army have both created policy to reduce the amount of C&D materials that end up in landfills.

- In 2006, the office of the Assistant Chief of Staff for Installation Management (ACSIM) issued a memo titled "Sustainable Management of Waste in Military Construction, Renovation and Demolition Activities" (US Army 2006). This memo required all military construction, renovation, and demolition projects to include in their contracts that a minimum of 50% by weight of the C&D waste generated should be diverted from the landfill.

- The Department of Defense (DoD) followed this initiative by issuing a memo reiterating the 50% diversion goal and setting a date for implementation of 2010 (DoD 2008).

- In 2009, President Barack Obama signed the Executive Order (EO) 13514 "Federal Leadership in Environmental, Energy, and Economic Performance" in an effort to make the federal government more sustainable (Obama 2009). This mandate extends the 50% diversion goal to all federal agencies, a goal which must be accomplished by fiscal year (FY) 2015.

Net Zero Installation Strategy

The Army Net Zero Installation Strategy was announced in 2011 (US Army 2011). The main goal of this strategy is to integrate sustainability practices at the installation level to preserve the flexibility to operate in constrained circumstances, either economical or environmental. The Army recognizes there are five inter-related steps to achieve net zero – reduction, repurpose, recycling and composting, energy recovery, and disposal. These steps are shown in their hierarchical order in Figure 1, starting with reduction.

The Net Zero Initiative's first action was to select Net Zero pilot installations by dividing the effort into three different categories: Net Zero Energy, Net Zero Water, and Net Zero Waste. Each category is defined below.

- A Net Zero Energy installation is an installation that produces as much energy on site as it uses.

- A Net Zero Water installation is an installation that limits the consumption of fresh water resources and returns the water back to the same watershed.

- A Net Zero Waste installation is an installation that reduces, reuses, and recovers waste streams, converting them to resource value with zero landfill.

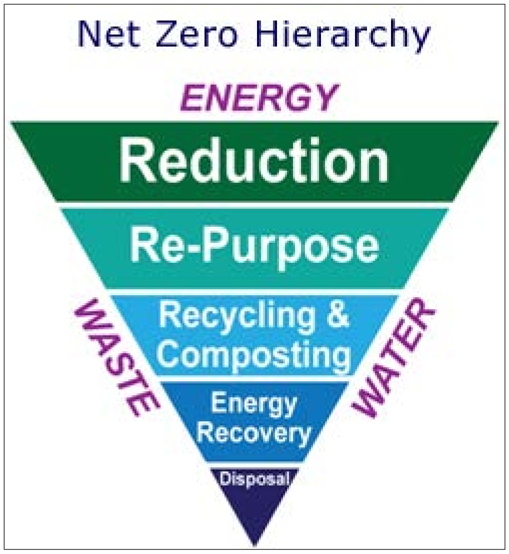

Figure 1. The Army's Net Zero installation strategy hierarchy.

Pilot installations for a single net zero goal should achieve their goal by FY 2020. The pilot installations shown in Table 1 were selected after an evaluation process from submitted applications.

Table 1. Army Net Zero pilot installations.

Net Zero Energy	Net Zero Water	Net Zero Waste
• Fort Detrick, MD	• Aberdeen Proving Ground, MD	• Fort Detrick, MD
• Fort Hunter Liggett, CA	• Camp Rilea, OR	• Fort Hood, TX
• Kwajalein Atoll, Rep. of the Marshall Islands	• Fort Buchanan, PR	• Fort Hunter Liggett, CA
• Parks Reserve Forces Training Area, CA	• Fort Riley, KS	• Fort Polk, LA

Net Zero Energy	Net Zero Water	Net Zero Waste
• Sierra Army Depot, CA	• Joint Base Lewis-McChord, WA	• Joint Base Lewis-McChord, WA
• West Point, NY	• Tobyhanna Army Depot, PA	• US Army Garrison Grafenwoehr, Germany
Integrated Installations (Net Zero Energy, Water and Waste)		
• Fort Bliss, TX • Fort Carson, CO		

Net Zero Waste

The concept of Net Zero Waste simply states that, during the course of any given year, no waste should go to the landfill. A combination of different waste management practices should be applied to accomplish this goal. These practices are divided in two main components——waste minimization and waste diversion. The waste minimization component of the Net Zero Strategy encourages installations to reduce the waste at the source by engaging in sustainable purchasing of materials that generate less waste, have less packaging, or are reusable or recyclable (i.e., “green procurement”). The second component, waste diversion, refers to the processes and technologies the installation can use to avoid waste going to the landfill. Examples of alternatives to landfill disposal, among many others, are reusing materials, recycling and composting, and waste-to-energy technologies.

Meeting Diversion Goals

Currently, most of the installations are meeting the mandated 50% C&D diversion goals by separating the concrete generated from demolition activities. Unfortunately, this does not mean that the materials are actually being reused on post. Most concrete material is either sent to an outside recycling vendor, and installations pay a small fee for this service. In other cases, the material simply is being stockpiled for future crushing. Some stockpiles have been sitting for years and have become very large. By not reusing the concrete debris on post, the installations are losing a valuable resource.

Concrete crushing as a means to reuse and recycle on post means both waste diversion and cost savings. By studying several installations practices, we have compiled those that proved to be most effective for both cost and logistics (See Appendix B). Here, we give an understanding of concrete crushing and the associated recycling and environmental concerns to further prepare installations to adopt the practice on post.

Facts about Concrete Crushing

There are different kinds of processes available to crush concrete. Compression and impact crushing are the most common processes used. The Environmental Council of Concrete Organizations reports that, in the United States alone, 61% of recyclers use jaw crushers for primary crushing and 43% use cone crushers for secondary crushing. Recyclers often prefer a jaw crusher because it can handle large pieces of concrete.

The following three crushers are the most commonly used in the concrete recycling industry:

- *Jaw crushers*: When using this system, the concrete is compressed by jaws between a stationary and moveable plate. The concrete is reduced in size as it travels down the length of the wedge between the two plates. These types of systems are used as primary crushers and typically produce a 4–8 in. minus product, which is usually used as fill or as the input to a secondary impact crusher.

- *Impact crushers:* To successfully accomplish concrete crushing, impactors use a spinning rotor with bars or hammers that fling the concrete into a solid plate, several plates, or rods. This type of system could be used as primary, secondary, and even tertiary crushers and produce typically an aggregate product of less than 2 in., used as base material in some parts of the country.

- *Cone crushers:* This equipment also uses compression to achieve concrete crushing. The concrete is compressed between two cone shaped plates. However, the size concrete fed to a cone crusher is typically less than 6 in. as they are used mostly as secondary crushers behind a jaw or impact type as primary. The product size produced by cone crushers typically is typically less than 1½ in.

Depending on the needs of the user, the concrete crushing equipment might be available in portable, mobile, and stationary configurations.

- *Portable concrete crushers* are mounted on rubber-tired chassis and towed to the site by truck (Figure 2). On site, they are moved by loaders or tugs.

- *Mobile concrete crushers* are carried to the site by truck and trailer but have their own onboard drive system; they are typically track driven (Figure 3).These units work well on sites where several moves are required.

- *Stationary concrete crushers* are systems that are permanently fixed to the ground. This type of crusher is typically used in a recycling yard where all material is trucked to the site.

Figure 2. Portable crushing plant at Fort Campbell.

Figure 3. Mobile concrete crusher at Fort Bragg.

Producing Crushed Concrete

The concrete crushing process consists of several steps that vary with the type of crusher used, but usually consists of removing, stockpiling, and grading the concrete product (Gabr et al 2011). After demolition, when concrete is reduced to manageable-sized pieces, it is manually inspected for large pieces of debris. The concrete is stockpiled either on site (Figure 4) or transported to the crushing facility. Concrete crushing operations are recommended to be done at warmer temperatures because the equipment could have mechanical issues if temperatures are below freezing.

Figure 4. Concrete crushing at Fort Campbell.

First, the primary jaws, cones, and/or large impactors crush the concrete rubble that enters the system. Depending on the type of crusher, the concrete rubble’s size can vary from 30 in. to 4 ft in diameter. Following initial crushing and removal of any steel, the larger material is fed into a secondary crusher that breaks the particles down to the maximum size required for each specification.

Secondary crushers are also popular among recyclers. After secondary crushing, the concrete will go through screening. Primary and secondary screens could be used, depending on the project, the equipment used, and the final product desired. A scalping screen will remove dirt and foreign particles. Then, a fine harp deck screen will remove fine material from coarse aggregate. To ensure the recycled concrete product is free of dirt, clay, wood, plastic, and organic materials, further cleaning is necessary. This is done by water floatation, hand picking, air separators, and electromagnetic separators.

Recycling the Reinforced Steel

Recycling the reinforced steel is a big part of the concrete crushing process. This work is usually done by magnetic separation (Figure 5); however, manual inspection is also recommended. Because there is good demand for recycled steel, the diversion rate is very high. It is very common for demolition contractors to extract and sell the reinforcing bars as ferrous scrap. Currently, the average price of scrap steel is $0.11 per pound. Usually, the reinforcing bars are melted down to create new steel products, which can include new reinforcing bars.

Recycling of reinforcement steel has increased throughout the years. The Steel Recycling Institute (2012) estimates that over 70% of reinforcing bars were recycled in 2010, compared to 47% in 2000. More than 7 million tons are recycled every year.

Figure 5. Removing reinforcing steel with a magnetic belt.

Stockpile Care and Concerns

Usually, most of the crushed concrete will end up stockpiled until being transferred to another facility or recycled on site. Another stockpile is sometimes formed by concrete waiting to be crushed (Figure 6). Care should be taken to avoid contamination of the stockpiles, either by external sources or by the soil underneath. The crushed concrete's condition and quality will depend greatly on maintenance of the stockpile.

Figure 6. Concrete stockpiled before crushing at Fort Bragg.

Crushed product should be segregated and stockpiled by size (Figure 7). In addition, the Illinois Department of Transportation (IDOT 2012) recommends providing stockpile pads and a properly maintained hauling road/plant area to assure that acceptable material is not contaminated prior to use. In addition, IDOT recommends sampling each stockpile for quality. As with any aggregate stockpile, care should be taken to avoid excessive moisture, especially during hot weather, to reduce the potential for secondary cementing.

Environmental concerns can also result from exposure of the stockpile to precipitation. Exposing mortar and unhydrated cement to moisture can lead to runoff that can be highly alkaline and also show trace amounts of heavy metals and other naturally occurring contaminants, according to a manual prepared by Applied Pavement Technology for the Michigan Department of Transportation (MDOT). While these contaminants demonstrate rapid depletion with time, the possibility of contamination is a fact worth pay attention to (MDOT 2011).

Figure 7. Concrete stockpiled by size after crushing at Fort Campbell.

Standards for Using Recycled Concrete Aggregate

AASHTO M147-65-UL, "Standard Specification for Materials for Aggregate and Soil-Aggregate Subbase, Base and Surface Courses"

This specification covers the quality and grading of virgin and recycled aggregate products for use in the construction of sub-base, base, and surface courses.

ASTM D2940, "Standard Specification for Graded Aggregate Material for Bases or Subbases for Highways of Airports"

For federal highway projects, all engineering properties for crushed concrete being used as a road base aggregate should comply with these standards for virgin aggregate (AASHTO 2009; ASTM 2004).

State-Level Standards

Also, departments of transportation in several states have their own standards for the use of crushed concrete. For example, IDOT has a policy that specifies quality, gradation, and stockpiling requirements. In order to use recycled concrete aggregate (RCA) in IDOT projects, the concrete must come from IDOT projects.

ACI 555R-01, "Removal and Reuse of Hardened Concrete"

This standard outlines different methods for complete and partial removal of concrete from different types of structures (ACI 2001). Safety, environmental impacts, and other aspects are covered. Some of the methods discussed are:

- hand tools
- hand-operated power tools
- vehicle-mounted equipment
- explosive blasting
- drills and saws
- non-explosive demolition agents
- mechanical splitters
- heat
- hydrodemolition

This standard also covers the production of aggregate from removed concrete for use in new concrete mixtures. It defines parameters and tests for quality; it also provides descriptions and literature citations regarding the effects that using RCA could have on concrete properties. According to the standard, some of the properties that could be affected by the use of RCA in concrete are strength variations, modulus of elasticity, and permeability (among several others).

Properties of Crushed Concrete

RCA looks like crushed stone (Figure 8). However, crushed concrete has many physical properties that vary from those of natural aggregates. In general, crushed concrete particles are more angular and have a rougher surface texture than natural aggregate. Roughly textured, angular, and elongated particles require more water to produce workable concrete than smooth, rounded, compact aggregate.

Figure 8. Crushed concrete aggregate.

The lightweight, porous cement mortar attached to RCAs causes crushed concrete aggregates to have a lower specific gravity and higher water absorption than comparable-sized natural aggregates.

The lower compacted unit weight of RCA compared with conventional mineral aggregates results in higher yield (greater volume for the same weight), which is therefore economically attractive to contractors.

One of the main issues surrounding the use of RCA in new Portland cement concrete production is the potential for reaction between the RCA and alkaline water. Alkali-silica reaction results in volumetric expansion, in which there is a high probability of internal fracturing and premature deterioration of the concrete. Where alkali-silica reactivity is of concern, the potential for deterioration should be evaluated (Recycled materials Resource Center: http://rmrc.wisc.edu/).

Chloride ions from marine exposure can also be present in RCA. Because of the use of deicing salts as a mechanism to control development of ice on pavement, there is a strong possibility that chloride ions will be present in recycled concrete aggregate. The presence of chloride ions in Portland cement concrete can adversely impact the reinforcing steel within concrete.

Note that these chemical-related concerns apply largely only to use of RCA in new concrete mixes or asphalt concrete. Many, perhaps most, of the uses for RCA (such as a roadbase or erosion control) are not subject to these limitations.

Snyder (1994) studied and compared the properties of the crushed concrete to the properties of natural aggregates. Given that the crushed concrete also contains part of the mortar portion and the virgin aggregate, some of the properties are affected. Table 2 presents a summary of Snyder's findings.

Table 2. Properties of natural aggregates vs. crushed concrete (taken from MDOT 2011made from Snyder 1994 data).

Property	Natural Aggregate	Crushed Concrete
Particle Shape and Texture	Well-rounded, smooth (gravels), to angular and rough (crushed stone)	Angular with rough surface.
Absorption Capacity	0.8%–3.7%	3.7%–8.7%
Specific Gravity	2.4–2.9	2.1–2.4
L.A. Abrasion Test: Mass Loss	15%–30%	20%–45%
Sodium Sulfate Soundness: Mass Loss	7%–21%	18%–59%
Magnesium Sulfate Soundness: Mass Loss	4%–7%	1%–9%
Chloride Content	0–2 lb/yd^3 (0–1.2 kg/m^3)	1–12 lb/yd^3 (0.6–7.1 kg/m^3)

Current State of Recycled Concrete Aggregate as an Aggregate Base

The Construction and Demolition Recycling Association (CDRA; www.cdrecycling.org), formerly known as Construction Materials Recycling Association (CMRA), published a white paper in November 2012 that documented the use and acceptance of RCA as an aggregate base across the United States (Jones 2012). The recycling association surveyed state materials engineers and found that 33 of 39 states indicated RCA was allowed as an aggregate base, and six states currently do not allow it. Most of the issues and concerns are related to leachate that can damage surrounding infrastructure. No environmental concerns were raised during the survey.

According to the survey results, those states that allow the use of RCA have different regulatory procedures and specifications to accept the product. However, like the federal requirements, most of the specifications are similar to those for virgin aggregate. Stockpiles also are regulated differently, depending on the state. The white paper recommends consistency in regulatory procedures within states to optimize the availability and cost of RCA.

Concrete Containing Lead-Based Paint

One big concern within potential users of crushed concrete is whether the crushed product is safe if it has been previously painted with lead-based paint (LBP). This safety concern was examined when CERL performed tests in 2010 to determine whether the lead content of crushed concrete could cause an environmental hazard that would require the paint's removal before recycling or reuse. The CERL studies concluded that due to the buffering capacity of concrete, the environmental risk is negligible from any lead contained in crushed concrete (Figure 9). However, the study also recommends that, for any given demolition project, some sampling be performed to ensure that any unusually high ratio of LBP to concrete is appropriately addressed (Cosper 2010).

Figure 9. Concrete containing lead-based paint being used as base for a parking lot in Fort Jackson.

Concrete Containing Polychlorinated Biphenyls in Paint

There are also environmental concerns regarding concrete contaminated with polychlorinated biphenyls (PCBs) due to high PCB contents in the paint. In the past, PCBs were added to industrial paints to increase heat tolerance and plasticity; thus some older painted walls might contain high concentrations of this chemical.

In 2001, technicians at Army industrial sites discovered PCBs in paint that coated many structures and process equipment. The concentration of PCBs in these paints ranged up to tens of thousands of parts per million. This discovery has limited some Army installations’ plans for the decontaminating process of equipment and buildings.

Researchers at ERDC’s Environmental Laboratory in Vicksburg, MS, performed a study of concrete from an Army Ammunition Plant. Representative core samples were collected and analyzed to determine whether PCBs from the paint could diffuse into the concrete material. The study concluded that diffusion from the PCBs was negligible, because no gradients in concentration with depth were observed in the data (Griggs and Larson 2011).

APPENDIX B:

POTENTIAL ARMY APPLICATIONS FOR CRUSHED CONCRETE

Concrete can be recycled in several ways. Last year, Jones (2012) reported an estimated 140 million tons of concrete were recycled annually in the United States and used mostly by state-level departments of transportation. The most common use for the recycled concrete is to be crushed for road base material. There is a wealth of information and guidance available from various sources regarding such practices. However, Army installations are faced with several logistical and regulatory limitations, such as road construction standards that won’t allow the use of crushed concrete as road base material in military installations. Given these limitations, other applications are presented here that are more viable alternatives for concrete recycling and reuse.

Fines from the crushing process may or may not be desirable, depending on the application. For erosion control and pipe bedding, fines are not desired because one wants to enable the flow of groundwater through the bed. However, for paving applications, compacting RCA that contains fines actually improves cohesion and makes a smoother, more stable surface.

Pavement Base

A base course is defined as the layer of material that lies immediately below the wearing surface of a pavement. The base course must be able to prevent overstressing of the subgrade and withstand the high pressures imposed on it by traffic. It may also provide drainage and give added protection against frost action when necessary.

Recycled aggregates can be (and are) used as granular base and subbase in road construction (Figure 10). In many applications, recycled aggregate will prove to be superior to natural aggregate for use as granular base. An estimated 85% of all cement concrete debris that is recycled is used as road base due to its availability, low transport cost, and good physical properties.

Figure 10. RCA used for granular base.

Trails and Fire Breaks

One of the most common uses for crushed concrete on installations is as a replacement for gravel on the common trails and fire breaks between training areas (**Error! Reference source not found.**). (Here, fire breaks refer to unpaved roads that cut through forest lands to slow the spread of fire and facilitate emergency access in case of a fire.) To ease access by vehicles on such unpaved areas, installations historically have often opted to use gravel. However, by using crushed concrete instead (Figure 12), installations can save a significant amount of money.

Figure 11. An unpaved fire road at Fort Jackson.

Figure 12. A fire road paved with crushed concrete at Fort Jackson.

Parking Lots

Using crushed concrete in unpaved parking lots is also an alternative to virgin gravel (Figure 13). There is considerable opportunity to utilize this application at several installations around the country. Caution should be taken to completely remove steel from the concrete during crushing, because any remaining loose pieces of steel rebar can damage tires.

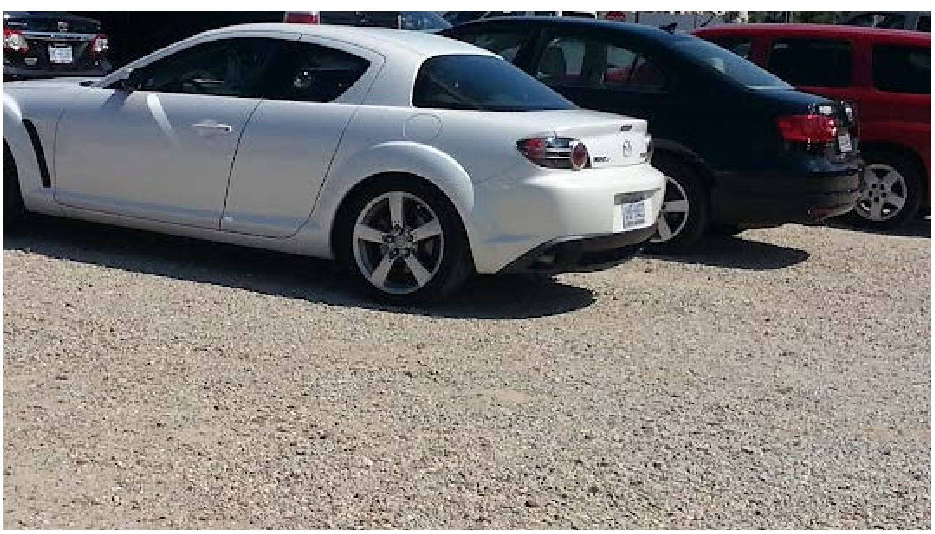

Figure 13. Parking lot made of crushed concrete at Fort Bragg.

Pipe Bedding

Underground utility bedding (pipe bedding) refers to the material installed to protect pipes from the loads they are subjected to in the trench where the pipe is located. Proper bedding placement is needed for adequate support by distributing the load over a larger area. Crushed concrete can be used for pipe bedding; however, some states regulate this type of application. Regulations should be reviewed before applying crushed concrete for this purpose.

Soil Stabilization

In general, soil stabilization is a process whereby soil properties are changed to improve engineering properties such as strength. Soil stabilization can be achieved by using different techniques like compaction, dewatering, and the addition of amendment materials. Soil amendments are considered when compaction and other techniques are not feasible due to materials such as rubble being present in the soil. This problem is usually presented in brownfield redevelopment sites.[1] Crushed concrete is a material that could be added as a soil amendment. Crushed concrete has been used as fill and base material in conjunction with cement reinforcement because it strengthens the soil and minimizes the footing dimensions and the stress influence that structures would have on the soil (Figure 14).

Figure 14. Soil cement and crushed concrete bed prepare an old landfill for redevelopment in Oregon (www.cement.org).

[1] Brownfields are abandoned or underused industrial and commercial facilities available for reuse.

Landscaping Projects

Recycled concrete can be used for landscaping projects, either as an ornament with different architectural texture or as a structural element such as a foundation for terraces and patios. One of the advantages of this application compared to others is that the concrete can be broken into pieces and does not have to be crushed to a specific diameter (Figure 15).

Concrete being reused for landscaping is commonly called “urbanite”. “Urbanite” can be seen in benches, garden walls, raised beds, paths, and patios; it can even be painted or stained for added decorative appeal by applying environmentally friendly products such as non-toxic soy-based stains (Figure 16). In addition to reuse of concrete, there are many other benefits for having raised garden beds, such as improved drainage and warmer soil for quicker germination in spring. It is actually very common to see “urbanite” advertised on Internet trading sites such as Craigslist, with the price very low or sometimes free (Tate n.d.).

Because the concrete is used mostly for ornamental purposes, the size of the concrete used in this application will greatly vary. It is recommended though, to use pieces from 1 to 3 sq ft. Pieces smaller than 1 sq ft require more care to lay and tend to be less stable. Pieces larger than 3 sq ft can be difficult to handle.

There are many organizations online (e.g., stopwaste.org) that provide guidance and creative ideas on how to use recycled concrete as a landscape material. For example, Figure 15 and Figure 16 are excerpted from an online landscaping blog to show how concrete recycled from a sidewalk retrofit project can be used as an ornamental pathway in a landscape project.

Figure 15. Potential source of urbanite (www.terranovalandscaping.com).

Figure 16. Stained urbanite garden (www.terranovalandscaping.com).

Other, Innovative Applications

Treatment of Acidic Groundwater

In their study, Regmi et al. (2011) used column experiments, filled with small particles of crushed concrete, to evaluate the reactive potential of recycled concrete to neutralize the acidity and the capacity to remove Al and Fe from acidic sulfate soil groundwater under accelerated flow conditions. The experimental results showed that recycled concrete can maintain an almost neutral pH for long periods and remove 100% of the Fe and Al. These results prove that crushed concrete can be a suitable material for permeable reactive barriers in remediation of acidic groundwater.

Geopolymerization

In an ongoing study conducted at the University of Arizona, geopolymerization is being used to optimize the reuse of concrete waste (Zhang 2012). Geopolymerization is a relatively new technology that transforms aluminosilicate materials (materials present in the concrete) into geopolymer. This technology involves a chemical reaction between the solid concrete in slightly elevated temperatures; the result of this reaction is a crystalline polymeric structure that has comparable properties to Portland cement. The Zahng study claims that this production method is simple and has a rapid mechanical strength development. If commercialized, this method has the potential to reduce energy-intensive Portland cement production by replacing the Portland cement with the cement produced from the waste concrete after it has been transformed by geopolymerization.

APPENDIX C:

INSTALLATION’S PERSPECTIVE ON CONCRETE CRUSHING

After contacting and visiting different installations during the course of this investigation, it is very clear that each installation has a unique experience with concrete crushing for subsequent reuse and recycle. Here is a summary of the concerns with facts and suggestions to help address them.

Factors Affecting Onsite Crushing

It might seem obvious that funding is the biggest issue when considering whether to crush the concrete on site. However, communication with other departments on post is equally as important. Potential users, such as road and grounds personnel, should be aware of the availability of the crushed concrete on site and encouraged (and, if possible, required) to consider the use of the crushed concrete before procuring virgin materials in their projects. Responsible personnel should engage in outreach efforts and survey the installation for potential sites where the crushed concrete can be used. This survey can be accomplished as well by investigating procurement of virgin gravel and basically approaching whoever is purchasing the gravel and if necessary clear any doubts about the quality and safety or the crushed material. Given the cost of purchasing virgin gravel varies from $18–$30 per ton compared to a cost of $10–$12 per ton for crushing, it should prove cost effective to crush concrete on site.

Another limitation, as described by (Napier 2012), lies in the fact that USACE and installation DPW personnel are frequently at odds when the expense of recycling concrete rubble would be borne by one party, but the benefit of using the RCA is accrued by another party. This may happen when a MILCON project’s requirements require recycling, the materials are not used in the project, and the installation receives “free” aggregate materials. Conversely, USACE personnel may consider offering the contractor government-furnished RCA, which was produced at DPW expense. Opportunities to recycle concrete may be lost if the parties cannot resolve the funding vs. benefit issue.

Options for Onsite Crushing

There are several options for crushing concrete on post:

- Contract the service for one single operation. Requesting end-of-year funds is a possibility to cover the cost. Note that some contractors require a minimum amount of concrete to accept a job, and this minimum could be up to 20,000–30,000 tons.

- Contract the services for periodic onsite crushing, on an as-needed basis. Consider the use of Qualified Recycling Program (QRP) funds to cover the costs. Equipment may be left at the work site throughout the contract period, or the contractor may elect to set up equipment when services are required and then tear down and remove equipment when services are not required.

- Purchase the crushing equipment using year-end funds, if available. The downside of procuring a crushing system is that personnel have to be trained to operate the system, and the equipment has to be periodically maintained to ensure optimal operation (e.g., the rotating surfaces on impact crushers).

Any of the above options requires a designated space to be available for stockpiling and crushing the material. Depending on how frequent the crushing operations are, a significant amount of space could be required. Some installations have separate areas for these operations, but others take the concrete material from the removal site and transport it to a prepared area at their landfill site.

An alternative to crushing on site is exporting the material to an external vendor. For a small fee, companies will pick up the concrete and resell it. This alternative is preferable for smaller installations where there is no onsite use for materials or the footprint for stockpiling.

Contract Considerations for Onsite Crushing

There are several items to consider when contracting a concrete crushing operation:

- The desired quantity and size to be crushed should be specified to the contractor.

- The steel reinforcement should be removed by the contractor and, if needed, should become the contractor’s property. The weight of steel recovered by the contractor should be reported to the installation.

- The installation should designate the stockpile area. However, the contractor should be responsible for preparing the stockpile site.

- The contractor should be responsible for stockpiling the crushed product at a prepared, specified location.

- The crushing site should be fenced. The contractor should be responsible for building this fence.

- The installation should inspect the crushed concrete for quality, ensure it is free from metals, and ensure it is in the desired size.

- The contractor should record the final weight of the crushed product and provide this information to the installation.

- The contractor should be responsible for all needed permits.

Benefits of Onsite Crushing and Reuse of Concrete

Projects on posts have demonstrated that reusing crushed concrete, instead of using virgin aggregates or virgin gravel, provides a benefit for the installation. Even if the contractor is responsible for concrete disposal instead of crushing, the landfill tipping fees will be embedded in the project’s final cost to the installation. For installations without a C&D landfill, tipping fees can vary depending on the area, representing an additional cost to manage the waste. For installations with a C&D landfill it could be only a matter of time before landfill capacity becomes an issue. In addition, even if the cost for virgin materials might be considered low in some areas, the crushed material would be available free, and no transportations costs will be incurred to get material to the installation. The Joint Service Pollution Prevention Opportunity Handbook estimated in 2003 that there is a payback period of about two years for the investment of crushing equipment (DoD 2003). However, this payback period will vary based on the area and the demand for material at the specific site.

Other Resources

The Government Services Administration's (GSA's) Environmental Strategies and Safety Division created the Construction Waste Management Database to promote responsible waste disposal. The database can be accessed via http://www.wbdg.org/tools/cwm.php and contains information on companies that haul, collect, and process recyclable debris from construction projects. Also see the Construction Waste Management page on that site, (http://www.wbdg.org/resources/cwmgmt.php) for guidance and resources covering multiple C&D materials and construction management practices.

The Joint Service Pollution Prevention Opportunity Handbook provides an online spreadsheet for calculating and preparing an Economic Analysis with the values for your site. This spreadsheet can be found on the following archived webpage: http://www.ec.gc.ca/planp2-p2plan/default.asp?lang=En&n=56875F44-1&offset=14&toc=show.

APPENDIX D:

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APPENDIX E:

ABBREVIATIONS AND CONVERSION FACTORS

Abbreviations Used

Abbreviation	Spelled Out
AASHTO	American Association of State Highway and Transportation Officials
ACI	American Concrete Institute
ACSIM	Assistant Chief of Staff for Installation Management
AR	Army Regulation
ASTM	American Society for Testing and Materials
C&D	construction and demolition
CDRA	Construction Demolition Recycling Association
CECW	Directorate of Civil Works, U. S. Army Corps of Engineers
CEMP	Directorate of Military Programs, U. S. Army Corps of Engineers
CERL	Construction Engineering Research Laboratory
CMRA	Construction Materials Recycling Association
CMU	concrete masonry unit
CONUS	Continental United States
DoD	Department of Defense
DPW	Directorate of Public Works
EO	Executive Order
ERDC	Engineer Research and Development Center
FRP	Facilities Reduction Program
FY	fiscal year
GSA	Government Services Administration

Abbreviation	Spelled Out
HQUSACE	Headquarters, US Army Corps of Engineers
IDOT	Illinois Department of Transportation
LBP	lead-based paint
MDOT	Michigan Department of Transportation
OACSIM	Office of the Assistant Chief of Staff of Installation Management
PCB	polychlorinated biphenyl
POC	point of contact
PWTB	Public Works Technical Bulletin
QRP	Qualified Recycling Program
RCA	recycled concrete aggregate
SI	International System
USACE	US Army Corps of Engineers

UNIT CONVERSION FACTORS

Multiply	By	To Obtain
cubic yards	0.7645549	cubic meters
feet	0.3048	meters
inches	0.0254	meters
pounds (mass)	0.45359237	kilograms
square feet	0.09290304	square meters
tons (2,000 pounds, mass)	907.1847	kilograms
yards	0.9144	meters