CHAPTER 5: PAVEMENT, MATERIALS, AND RECYCLING

Despite the increase in public infrastructure investments, pavements and other elements are decaying faster than they can be renewed, in many cases. Factors have included insufficient funds, population growth and increasing infrastructure demands per capita as lower density development spreads out into new areas, tighter health and environmental requirements, poor quality control having led to inferior installation, inadequate inspection and maintenance, and lack of consistency and uniformity in design, and construction and operation practices. The increased burden on infrastructure can hasten and aging process and increase the social, fiscal, and environmental costs with needed repairs.

Increasingly state DOTs are employing pavement management systems to ensure that resources are targeted where they will produce the greatest effect—conservation of existing resources and infrastructure—in the most efficient or cost-effective manner. This enables transportation dollars to go further, and can lead to prolonged infrastructure life and greater periods of time between more environmentally intrusive reconstruction projects.

Environmental stewardship is also practiced in the course of recycling pavement and DOT waste products, and using other recycled materials in DOT pavements and roadside structures. Recycling directly addresses energy conservation needs in construction and maintenance as well.

5.1 Preventative Maintenance and Pavement Management Systems

Timing is critical in preventive maintenance, as “preventive maintenance is a program strategy intended to arrest light deterioration, retard progressive failures, and reduce the need for corrective maintenance and service activities.”(i) Preventive strategies for flexible pavements include seal coats such as chip seals, slurry seals, micro surfacing, thin overlays, and crack sealing. Rubberized asphalt concrete (RAC) usage can extend pavement life and help to address waste and landfill issues while providing a smoother ride, better resistance to cracking than other types of pavement surfaces, and less frequent maintenance. In addition, RAC has the potential to reduce noise levels to a point where a soundwall may not be needed in some locations. Preventative maintenance (PM) treatments for concrete pavements include crack and joint sealing, dowel bar retrofit, partial depth slab repairs, and diamond grinding for smoothness and improved pavement texture. All of these treatments reduce the amount of water that may infiltrate the pavement, slow the rate of deterioration, or correct surface roughness. Timely application can maintain or extend a pavements service life five to ten years or longer before significant maintenance effort is required. Surface treatments also help prevent raveling and improve surface friction properties, but can accelerate vapor action and stripping when applied to aged and open pavements.(ii)
Caltrans determined that for every $1 spent on Preventative Maintenance or Capital Preventative Maintenance (CAPM), $3 to $20 is saved if the treatment is applied at the right time, before the pavement deteriorates into a major rehabilitation or reconstruction project. In addition, reconstruction in urban areas is more expensive. Instead of the estimated $200,000 per lane mile, the costs may exceed $1 million per lane mile. In contrast, a PM strategy will typically cost $50,000 to $100,000 per lane mile, covering many more miles for the equivalent dollar. A significant savings for PM comes from a reduction in time spent in design and construction. Prior to PM, for example, Caltrans did as much Corrective Major Maintenance as the limited budget allowed until full rehabilitation, or, in the worst-case, reconstruction was needed. Time spent waiting until the pavement can by fully rehabilitated allows time for the pavement condition to deteriorate further. Since PM projects are pavement only, they require less design time and can be delivered faster. During construction, pavement surfaces are renovated, using thinner treatments, which contributes to faster production rates. Also, less construction working days reduces the disruption to the traveling public and less disturbance to roadside environments.

The factors affecting pavement life include a variety of site conditions, including traffic, climate, and paving material. Condition surveys help predict the occurrence of distress (including density of cracking and the average level of crack edge deterioration), select appropriate maintenance, and program such activities before further deterioration occurs. When crack densities are low to moderate, crack sealing is effective; however, as densities progress from moderate to high, surface treatments are more effective. There are three basic techniques for surface treatment of cracked pavements: slurry, chip seals, and thin hot mix overlays. Selection of the best treatment is a function of the existing pavement condition. Results from the Strategic Highway Research Program (SHRP) suggest the following:

- Slurry seals perform best when applied to pavements with little or no cracking.
- Chip seals perform well on cracked pavements, but add no structure and do not improve rideability.
- Thin hot mix overlays perform better than other treatments on pavements with higher roughness and/or rutting. They are also effective as a seal, and they prevent raveling.

The Federation of Canadian Municipalities and the Canadian National Research Council also have developed Guidelines for Sealing and Filling Cracks in Asphalt Concrete Pavement: A Best Practice by the National Guide to Sustainable Municipal Infrastructure. Other publications included in their National Guide are Timely Preventive Maintenance for Municipal Roads, a primer on preventative maintenance methods, setting priorities, and cost analysis; Priority Planning and Budgeting Process for Pavement Maintenance and Rehabilitation, an eight-step approach to budgeting and timely maintenance; and Alberta Transportation’s Guidelines for Assessing Pavement Preservation Strategies. 

Pavement management systems have helped DOTs prioritize improvements and document the cost-effectiveness of preventative maintenance. In a shift to a more proactive road maintenance strategy, Nevada DOT is prioritizing projects based on how quickly roads are deteriorating or prediction models, not on the basis of their current condition. Prevention strategies are ranked by life-cycle cost, not initial cost.
deployed cold-in-place recycling based on a sophisticated lifecycle cost comparison; the state optimized its projects by assigning roads to five categories based on volume and environmental conditions. Caltrans is among the state DOTs publishing a State of the Pavement Survey. Pavement condition is evaluated using ride score (IRI) and the pavement surface condition. The PMS provides a systematic, objective evaluation of pavement condition for identification of maintenance and rehabilitation needs and projects, and then prioritization of those projects. The tool can help a DOT track progress toward reducing total pavement needs to specified target levels as well as in improving pavement conditions overall.

5.2 STORMWATER MANAGEMENT IN PAVING OPERATIONS, GRINDING, AND PAVEMENT MAINTENANCE

Water quality discharges from paving operations, grinding and maintenance are sometimes a concern. In pavement preservation projects with little soil disturbance, project managers may still require BMPs to be installed in spot locations where wetlands or waterways are immediately adjacent to the roadway. Pick up brooms may be used to clean surfaces of excess aggregate after a chip seal project instead of a rotary type broom, which can push aggregate toward nearby waters or streams.

Some state environmental agencies have identified issues with runoff from diamond grinding. Diamond grinding consists of removing surface irregularities from concrete pavements that are often caused by faulting, curling, and warping of the slabs. The main benefits of properly using this technique include smoother ride, reduced road noise, and improved friction. Diamond grinding can be used as a stand-alone rehabilitation technique.

Other water quality control measures are described elsewhere in this report, particularly in sections:

- Section 3.7: Design Guidance for Stormwater and Erosion & Sedimentation Control
- Section 4.5: Construction in Streams, Wetlands, and Other Environmentally Sensitive Areas
- Section 4.6: Erosion and Sedimentation Control in Construction
- Section 7.2: Avoiding and Minimizing Impacts to Fish and Wildlife And Enhancing Habitat during Bridge Construction and Maintenance
- Section 10.4: General Maintenance Near Waterbodies

Missouri DOT Guidelines for Preventing Discharge from Diamond Grinding Operations

Missouri DOT (MoDOT) developed the following guidelines for preventing discharge of the slurry from entering waters of the state from diamond grinding operations.

- No discharge of water/lime slurry will be allowed to enter “waters of the state”.
  - “Waters of the state”, all rivers, streams, lakes and other bodies of surface and subsurface water lying within the boundaries of the state which are not
The slurry should not be discharged to drainage ways, non-vegetated areas or anywhere storm water runoff is likely to occur.

Discharge of the slurry should be stopped at least 25 feet from creeks and rivers on slopes less than 12 percent and 50 feet on slopes 12 percent to 25 percent in areas with healthy vegetation on the road right of way and at least 12 feet from the bottom of the ditch.

On sites where there is sparse or no vegetation to control the movement of the slurry, alternatives that may be used include:
  o Pump the slurry into tankers and hauled to an area where it can be spread as a lime supplement. This method will require additional tankers and land close to the project site.
  o Incorporate the slurry into the soil on the right of way next to the road where it will not impact waters of the state, highway or shoulders.

The Area Engineer must approve any other method of application or use of the slurry. An Environmental Compliance Coordinator should be contacted for guidance on the use of alternative methods.

Precautions must be taken at all times to prevent the slurry from entering the waters of the state. Should improper application occur which may result in a discharge of lime slurry to the waters of the state, the contractor shall immediately remove the slurry and notify the Area Engineer.

5.3 Flexible Pavement/Asphalt

Flexible pavement (asphalt) maintenance activities provide public safety, protect personal property, preserve the state’s capital investment, and maintain a riding quality that is satisfactory to the traveling public. Road surface maintenance typically involves the use of asphalt and other materials to create impervious surface areas or to repair existing road surfaces. Surface and inlay repair includes all repairs of road bases, surface, and shoulder irregularities, including asphalt and concrete surfaces. Asphalt plant production includes production of asphalt for patching materials, staging, moving, stockpiling and setup of asphalt plants.

The basic input materials used in asphalt preparation are hot liquid asphalt and aggregates, such as sand and gravel. Some smaller quantities of recycled asphalt pavement, sulphur, rubber, lime and foundry sands may also be incorporated into the mix. The type of process technology used is important because it also affects quantity and quality of resulting air and waterborne contaminants. Air emissions from these mixing operations are a concern primarily because of high hydrocarbon, nitrous oxides, sulphur dioxide, carbon monoxide and particulate concentrations. Waterborne contaminants originate in aggregate storage areas, air scrubbers, and vehicle wash-down areas. Airborne contaminants are typically removed using filtering baghouses, while waterborne contaminants are usually removed in large settling ponds. Stormwater collected from aggregate storage areas and wastewater from the spraying down of HMA transport
vehicles should be directed to a contaminated water treatment area. Treatment may consist of catchment basins and or settling ponds and oil-water separators. Treated water should then be discharged to local storm sewers or to a nearby river. Settled fines in the catchment basins should be removed and landfilled after being left to dry out as much as possible. (vii)

A pollution prevention plan can encourage examination of existing process and pollution prevention technologies and consideration of upgrades or equipment improvements. Management practices play a key role in pollution prevention. Opportunities for pollution prevention through management, such as installing hot liquid asphalt storage tank high-level alarms, using soap instead of diesel for washing down trucks, and partially or completely containing raw aggregate storage areas, are suggested. Waste materials such as used baghouse socks, collected dust materials and dried sludge from settling ponds should be treated and recycled where possible. If there are no other alternatives, the materials should be disposed of in an environmentally responsible manner.

There are opportunities for changes on the most basic level in the asphalt production industry, namely changes to the input materials and products made. Because of the strict specifications and gradations required for quality HMA production, certain sands and gravels are required as the bulk of aggregate materials. However, other materials can be added to the basic aggregates without compromising the final HMA quality. Such materials are broken asphalt (taken from a road that has been ripped up), sulphur, rubber and foundry sands. Broken asphalt, known in the industry as RAP (recycled asphalt pavement), can almost always be incorporated into HMA and meet the required gradation.

**Asphalt Cement Crack and Joint Grinding and Digouts/Structural Repair**

Flexible pavement is susceptible to cracking, and the cracks should be repaired to prevent the entrance of moisture into the subgrade. In some instances, cracks need to be cleaned prior to filling. A stiff broom, compressed air, or a gouge-type tool or mechanical router are typically used to clean the cracks. Cracks are then filled with rubberized sealant, emulsion or liquid asphalt. Fine sand may be applied to the surface of the crack after it has been filled. The repair of slippage cracks requires the removal of the surface layer prior to patching with mixed asphaltic concrete. Other subtasks associated with this activity include vehicle operation, disposal of removed material and grindings, and post-sweeping.

Structural pavement failure (digouts), pavement grinding and paving applies to significant repairs to structural pavement that require removal of the roadway surface using graders and grinders. Subtasks associated with this activity include vehicle operation, asphalt removal, disposal of removed material and grindings, pre- and post-sweeping.

Pollutant sources associated with this work include leaks, spills, dust and grinding can result in release of fuel, asphalt release agents, hydraulic fluid, oil, sediment, aggregate material and asphalt grindings. Water may be applied during grinding or post-sweeping operations. Recommended environmental stewardship practices to control and minimize pollution include standard best management practices (BMPs) such as illicit connection/illicit discharge reporting and removal, scheduling and planning, illegal spill discharge control, vehicle and equipment fueling, vehicle and equipment maintenance,
solid waste management, hazardous waste management, liquid waste management, sanitary/septic waste management, safer alternative products, spill prevention and control, and sweeping and vacuuming. (viii)

**Asphalt Paving**

Asphalt work involves the patching or resurfacing of the roadbed with a mixture of mineral aggregate and bituminous binder. The purpose is to repair degraded asphalt surfaces. The primary subtasks include equipment operation, pre- and post-sweeping, asphalt application, binder application (tack coating), pavement application and compaction roller operation. Pollution may occur from leaks, spills and stockpiled material from sweeping. Potential pollutants may include: fuel, asphalt release agents, hydraulic fluid, oil, sediment, asphalt and petroleum-based binders. The use of water during sweeping, asphalt application, binder application, compaction roller operation and evaporative cooling must be controlled to prevent unpermitted non-stormwater discharges. Recommended environmental stewardship practices include: illicit connection/illicit discharge reporting and removal, scheduling and planning, illegal spill discharge control, vehicle and equipment fueling, vehicle and equipment maintenance, solid waste management, hazardous waste management, liquid waste management, sanitary/septic waste management, material use, safer alternative products, paving operations procedures, spill prevention and control, sweeping and vacuuming and water conservation practices. (ix)

The asphalt plant and other facilities should be operated in such a manner so as to safeguard the air and water resources by controlling or mitigating environmental pollution in accordance with all Environmental legislation. Additional environmental stewardship practices that can minimize environmental impacts from paving operations include the following:

- Ensure that contractors and/or staff who fuel and operate asphalt plants have an adequate spill plan and materials for spill containment.
- Establish mixing plants outside of riparian corridors, site location to be approved by the Region Environmentalist/Biologist and/or resource agencies.
- Use commercial asphalt plants for asphalt supply, where economically feasible.
- Provide areas for truck chute cleanout with proper containment of wet concrete.
- Protect inlets and catchments from fresh concrete during inclement weather.
- Where possible, perform surface work in dry weather, to minimize any runoff of potentially hazardous material.
- Do not use volatile organic compounds (VOCs) to liquefy asphalt except for asphalt used in:
  - Long-life stockpile material for patching and repair.
  - Low temperature applications from October 16 to May 1.
  - Penetrating prime coat for preparing an untreated absorbent surface to receive asphalt.
• Pre-treat all grader blades, truck beds, tires, asphalt distributors, or other equipment and tools with vegetable oil or other approved proprietary product as a release agent for asphalt. Hand sprayers can be used to apply vegetable oil.

Emergency Pothole Repairs

Emergency pothole repairs are unscheduled, emergency repairs necessary for the protection of the traveling public. Pothole repairs involve the filling and resurfacing of potholes along flexible pavement portions of roadways and highways to eliminate holes and cuts in the pavement. Because of the unscheduled nature of the repairs, the applicability of BMPs is limited to planning measures that facilitate emergency response in an environmentally sound manner.

• The potential for spilled patch material should be managed through safer alternative products when available, and appropriate vehicle and equipment maintenance and fueling practices.

Sealing Operations

Seal coats may be required for asphalt pavement due to erosion or oxidation of the roadway surface. Coatings may also be used to reduce the permeability of the surface or to reduce slipperiness. Seal coats include fog seal (emulsion and water), sand seal (asphalt and sand), chip seal (emulsion and rock screenings) and slurry seal (emulsion, additives, water and aggregate). Chip sealing provides a bituminous surface treatment (BST) to maintain and extend longevity for roads, and underlies many other maintenance and operations activities, such as shoulder rehabilitation, vegetation and shoulder projects. Crack sealing and surface treatments can extend the useful life of a pavement and delay the need for more costly or environmentally intrusive repairs. When crack densities are low to moderate, crack sealing is effective; however, as densities progress from moderate to high, surface treatments such as chip sealing are more effective.

Primary subtasks include pre- and post-cleaning, seal application, sand or aggregate application and compaction roller application. Associated subtasks include equipment operation. Potential pollutant sources include leaks, spills, dust, material tracking and excess release agent. These pollutants can release fuel, asphalt release agents, hydraulic fluid, oil, sediment, aggregate material and asphalt emulsion. Water may be applied during post-sweeping operations and needs to be managed to prevent polluted discharge. Much research has been performed in the United States and abroad on the materials, design, construction techniques, and effectiveness of chip seals in practice. Louisiana Department of Transportation and Development chip seal practice research was completed in 1998, South Dakota completed research on chip seal best practices in 2000; and Oregon DOT chip seal research; however, environmental stewardship recommendations particular to this paving practice have not been explicitly addressed. Research is being summarized through a survey of BMPs and a research synthesis, started in fall 2003 with anticipated publication in 2005. According to the Project Investigator, the only environmental practice found was wetting the aggregate to reduce dust; however, this practice may not be included in the synthesis as wetting the aggregate can degrade adhesion.
DOTs have employed the following environmental stewardship practices primarily to control water related discharges: illicit connection/illicit discharge reporting and removal, scheduling and planning, illegal spill discharge control, vehicle and equipment fueling, vehicle and equipment maintenance, solid waste management, hazardous waste management, liquid waste management, sanitary/septic waste management, material use, paving operations procedures, safer alternative products, spill prevention and control, sweeping and vacuuming and water conservation practices. (xii)

The Montana Department of Transportation (MDT) developed the following Sanding and Chip Seal Material Specifications for PM-10 Nonattainment Areas, to control air quality: (xiii)

- Furnish aggregate surfacing materials free of deleterious material except as permitted.
- Do not use scoria (fired clay commonly found in conjunction with burned coal in the lignite fields of the state) as aggregate to be bituminized.
- Ensure no combination of shale, clay, coal, and soft particles exceed 3.5 percent.
- Ensure the aggregate is free of wood and other plant material.

For Crushed Top Surfacing Type “Washed Sand,” MDT meets the following requirements for crushed top surfacing type “A”, including added binder or blending material: (xiv)

- Dust Ratio: Ensure that portion passing the No. 200 sieve does not exceed two-thirds of the portion passing the No. 40 sieve.
- Ensure the maximum liquid limit and plasticity index for the material passing the No. 40 sieve is 25 and 6 respectively.
- Ensure the composite aggregate is free of adherent films of clay and other matter that prevents the aggregates thorough coating with bituminous material. Ensure the bituminous material adheres to the material upon contact with water.
- Ensure that when the aggregate is to be bituminized, both the material source and the composite aggregate have a volume swell not exceeding 10 percent and not showing cracking or disintegration.
- Do not remove intermediate sizes from the material during production, unless authorized in writing.
- Ensure the aggregate has a wear factor not exceeding 50 percent at 500 revolutions.
- Ensure at least 35 percent by weight of the aggregate retained on the No. 4 sieve has at least one mechanically fractured face.

For cover material, MDT: (xv)

- Ensures the material for Grades 1A through 4A are non-plastic. For Grade 5A the liquid limit and plasticity index for the material passing the No. 40 sieve cannot exceed 25 and 6 respectively.
- Ensures the composite aggregate is free of adherent films of clay, vegetable matter, frozen lumps, and other extraneous matter that prevents thorough coating
with bituminous material. Ensure the bituminous material adheres to the material upon contact with water. Ensure no combination of shale, clay, coal, and soft particles exceed 1.5 percent.

- Ensures the aggregate has a wear factor not exceeding 30 percent at 500 revolutions.
- Ensures at least 70 percent by weight of the coarse aggregate for Grades 1A through 4A have at least one fractured face. Ensure at least 50 percent by weight of the coarse aggregate for Grade 5A has at least one fractured face.

**Asphalt Equipment Cleaning**

Diesel fuel used to be the product of choice to clean and pretreat equipment when working with bituminous pavement; however, environmental regulations prohibit dumping or spilling diesel or asphalt. The following policy is the best known management practice when asphalt cleaning is necessary.\(xvi\)

- Eliminate diesel as a releasing or cleaning agent and use environmentally sensitive cleaning and releasing agents.
- Spray the beds down with vegetable oil after each load using just a thin stream at the top of the bed, it will run down and coat the entire side, then put one coat on the floor. Spray once as needed. At the end of the day there may be some mix on the tailgate, spray a thin bead around the top; the next day the mix should remain soft and come off with the first load.
- Spray vegetable oil on the grader blades once a day or as needed.
- Spray it down with the vegetable oil during the day, then clean it with a citrus based cleaner in the evening only as needed.
- The asphalt distributor bar may need to be coated with vegetable oil after every spray.
- Using vegetable oil on tools such as rakes and shovels works well, the mix does not build up on them, and what does remain can be easily tapped off.
- Carry adequate erosion control supplies (diapers, kitty litter, shovels, etc.) to keep materials out of water bodies.
- Use heat sources to heat and clean tack nozzles during operations.
- Contain all products (including the cleaning product and the contaminated asphalt residue cleaned from the equipment) during cleaning using tarps, sand pads, pails or other collection methods to avoid spillage or accidental release of cleaning products.
- When cleaning the distributor bar, always catch any diesel or asphalt. Use a tray and recycle the diesel or asphalt into the tank, then reverse the pump to clean out the piping and snivies or reverse the pump to suck all the asphalt and diesel back into the tank. Consult the asphalt distributor’s operations manual for the correct method to reverse suction.
- Do not clean equipment or tools near streams, ponds, or drainage structures.
• Remove pieces of asphalt by scraping or other mechanical means, if possible, prior to application of a cleaning agent. Asphalt removed solely by mechanical methods is disposed of as construction and demolition debris.
• Use a minimal amount when a petroleum product is used for cleaning and recover all of the cleaning product.
• Use hand sprayers or other similar devices to minimize the amount of petroleum product applied.
• Report releases of petroleum products.

**Pavement Disposal**

• Pavement should be recycled whenever possible.
• Contaminated sand, soil, asphalt pavement residue, and other debris containing petroleum products resulting from activities such as paver cleaning with petroleum products should be handled as petroleum contaminated soil/debris and should be disposed at an authorized disposal site.
• Recognizable uncontaminated broken concrete and asphalt from demolition activities or excess material from a project should be taken to an off-site disposal facility or to a construction and demolition waste processing facility and/or not disposed of within 30 meters (100 feet) of wetlands, archaeological sites or other sensitive environmental areas.

5.4 CONCRETE INSTALLATION AND REPAIR

Rigid pavement maintenance activities are designed to provide safety, preserve the state’s capital investment and maintain a riding quality that is satisfactory to the traveling public. Road surface maintenance typically involves the use of concrete and other materials to create impervious surface areas or to repair existing road surfaces. Pollution control activities focus on ensuring that removed materials and Portland cement concrete wastes remain controlled and are not released to the environment. Environmental stewardship practices for ready mix concrete operations include, and were initially developed for the Frasier Basin, in British Columbia: (xvii)

• Reduction of use of toxic substances, raw materials and nonrenewables.
• Reuse of recovered raw material, products and hazardous substances.
• Elimination or minimization of environmental releases.
• Recycling of recovered materials off-site.
• Treatment of non-recoverable waste with a focus on recovery and minimization of residues.
• Safe disposal of wastes.
• Safe handling of chemicals and products to ascertain that no site contamination or sudden releases occur.
The questions below may be used as performance measures in evaluating sustainability. The checklist items also describe recommended environmental stewardship measures: (xviii)

**Reduction of Use of Toxic Substances, Raw Materials and Non-renewables**
- Are preventive measures in place to avoid “off-spec” concrete, (e.g., periodic testing of scales, batch gate operation, etc.)?
- Is an operator’s manual available?
- Is regular operator training provided?
- Is water conservation practiced by restriction of freshwater uses to purposes such as, truck exterior washoff, hot water production, and batch waters for high quality concrete?
- Are flow controls installed on freshwater sources?

**Reuse of Recovered Raw Material, Products and Hazardous Substances**
- Are volumes of returned concrete minimized (i.e., less than 2.5 percent of total production volume)?
- Is all returned concrete either reused (precast products, road base, etc.) or recycled (reclaimed)?
- Are all air pollution control residues reused?
- Are all drum washout solids reused or recycled?
- Are settling basin sludges reused or recycled?
- Is 100 percent of the process water (drum washout, truck wash) reused?
- Is collected yard stormwater used for washdown, etc.?

**Elimination or Minimization of Environmental Releases**
- Are spills of cement and concrete cleaned up immediately?
- Is the process area paved and curbed to collect processing water for treatment and/or recycling?
- Is the pavement and curbing in good condition (i.e., no cracks)?
- Is the size of the processing area minimized and/or roofed to reduce exposure to rainfall?
- Is yard stormwater diverted from the process area?
- Are oil separators installed in truck wash areas and other areas where oil releases may occur?
- Are measures taken to ensure proper dust control during transfer of cement and fly ash?
- Are aggregate piles designed to minimize fugitive dust control (e.g., minimal surface area, storage bins, covers)?
• Are high vehicle traffic areas paved?
• Is the traffic system controlled (e.g., low speed limits, one-way traffic to separate dirty from clean vehicles)?
• Are paved portions swept to remove accumulated dust?

Recycling of Recovered Materials Off-site
• If all concrete and sludges are not recovered on-site, are the materials used off-site (e.g., road base)?

Treatment of Non-recoverable Waste with a Focus on Recovery and Minimization of Residues
• Is there a system (e.g., settling basin) for treatment of excess water?
• Does the treatment system enable pH control?
• Is the process area minimized (i.e., \(<10\) percent of total yard area)?
• Does routine monitoring of effluent quality occur?
• Is the wastewater holding basin of sufficient volume to manage all effluent in high precipitation events?
• Can concrete fines and aggregates be removed from the basins?
• Is unusable sludge disposed of in approved facilities?
• Are admixture and other chemical containers returnable to the supplier?
• Are all chemicals no longer in use removed from the site?

Safe Disposal of Wastes
• Are lead batteries, solvents, waste oils, etc., stored in secure locations?
• Are lead batteries, solvents, waste oils, etc., recycled?
• Are operating procedures for waste disposal adequately defined?
• Has management confirmed that approved facilities are used for waste disposal?
• Is all documentation at hand for transport manifests, certification of destruction, etc.?

Safe Handling of Chemicals and Products to Ascertain That No Site Contamination or Sudden Releases Occur
• Are aboveground piping and valves visible and labeled?
• Are tank materials and designs as per all applicable codes and manufacturers’ recommendations?
• Are spill response equipment, absorbents and personnel protection equipment provided?
• Is worker training for spill response provided?
• Are signs in place to identify contents of bulk tanks and drums?
**Portland Cement Crack, Patch, and Sealing**

Cracks and joints in Portland cement concrete pavement should be filled to prevent the entrance of moisture into the subgrade. A stiff broom or compressed air are sometimes used to clean cracks prior to sealing. Asphaltic and rubberized sealants are used to fill the cracks; then sand may be applied. Other subtasks associated with this activity may include vehicle operation and post-sweeping. Leaks, spills, excess emulsion and dust can release pollutants such as fuel, asphalt release agents, hydraulic fluid, oil, sediment, asphalt and rubberized sealant. Recommended environmental stewardship practices to control such discharges include illicit connection/illicit discharge reporting and removal, scheduling and planning, illegal spill discharge control, vehicle and equipment fueling, vehicle and equipment maintenance, solid waste management, hazardous waste management, liquid waste management, sanitary/septic waste management, material use, safer alternative products, spill prevention and control, and sweeping and vacuuming. (xix)

The following general practices should be employed for patching, resurfacing, and sealing:

- Schedule patching, resurfacing and surface sealing for dry weather.
- Stockpile materials away from streets, gutter areas, storm drain inlets or watercourses.
- During wet weather, cover stockpiles with plastic tarps or berm around them if necessary to prevent transport of materials in runoff.
- Pre-heat, transfer or load hot bituminous material away from drainage systems or watercourses.
- Where applicable, cover and seal nearby storm drain inlets (with waterproof material or mesh) and maintenance holes before applying seal coat, slurry seal, etc. Leave covers in place until job is complete and until all water from emulsified oil sealants has drained or evaporated. Clean any debris from covered maintenance holes and storm drain inlets when the job is complete.
- Prevent excess material from exposed aggregate concrete or similar treatments from entering streets or storm drain inlets. Designate an area for clean up and proper disposal of excess materials.
- Use only as much water as necessary for dust control, to avoid runoff.
- Sweep, never hose down streets to clean up tracked dirt.
- Use a street sweeper or vacuum truck.
- Do not dump vacuumed liquid in storm drains.
- Catch drips from paving equipment that is not in use with pans or absorbent material placed under the machines. Dispose of collected material and absorbents properly.
Mudjacking and Drilling

Mudjacking is necessary for the maintenance and repair of rigid type surfacing, its associated base and any Portland concrete cement shoulders less than two feet in width. A Portland cement and pozzolan grout mixture is pumped below the slab (i.e., mudjacking) to replace lost or settled base material. Subtasks include vehicle and equipment operation, drilling, mixing, and pumping. Potential pollutant sources such as leaks, spills and concrete washout may result in the release of pollutants such as fuel, hydraulic fluid, oil, sediment and concrete. Water applied during drilling and pumping operations must be controlled to prevent unpermitted non-stormwater discharges. Recommended environmental stewardship practices to control discharges include: illicit connection/illicit discharge reporting and removal, scheduling and planning, illegal spill discharge control, vehicle and equipment fueling, vehicle and equipment maintenance, solid waste management, liquid waste management, sanitary/septic waste management, concrete waste management, material use, safer alternative products, spill prevention and control, sweeping and vacuuming and water conservation practices.  

Concrete Installation and Slab and Spall Repair

Spalling (i.e., chipping of Portland cement concrete surfaces), slab cracking and settlement are common problems associated with Portland cement concrete pavement that require repairs. Subtasks include vehicle operation, repair and cleaning (may include use of a compressor, jackhammer or sawcutting), curing and the disposal of removed materials. Leaks, spills and concrete washout may cause pollution from fuel, hydraulic fluid, oil, sediment and concrete. Water applied during curing operations should be controlled to prevent unpermitted non-stormwater discharges. Recommended environmental stewardship practices include: illicit connection/illicit discharge reporting and removal, scheduling and planning, illegal spill discharge control, vehicle and equipment fueling, vehicle and equipment maintenance, solid waste management, hazardous waste management, liquid waste management, sanitary/septic waste management, concrete waste management, material use, safer alternative products, spill prevention and control, sweeping and vacuuming and water conservation practices.  

For concrete installation and repair also:

- Schedule asphalt and concrete activities for dry weather.
- Take measures to protect any nearby storm drain inlets and adjacent watercourses, prior to breaking up asphalt or concrete (e.g. place san bags around inlets or work areas).
- Limit the amount of fresh concrete or cement mortar mixed, mix only what is needed for the job.
- Store concrete materials under cover, away from drainage areas. Secure bags of cement after they are open. Be sure to keep wind-blown cement powder away from streets, gutters, storm drains, rainfall, and runoff.
- Return leftover materials to the transit mixer. Dispose of small amounts of hardened excess concrete, grout, and mortar in the trash.
• Do not wash sweepings from exposed aggregate concrete into the street or storm drain.
• Collect and return sweepings to aggregate base stockpile, or dispose in the trash.
• When making saw cuts in pavement, use as little water as possible and perform during dry weather.
• Cover each storm drain inlet completely with filter fabric or plastic during the sawing operation and contain the slurry by placing straw bales, sandbags, or gravel dams around the inlets.
• After the liquid drains or evaporates, shovel or vacuum the slurry residue from the pavement or gutter and remove from site. Alternatively, a small onsite vacuum may be used to pick up the slurry as this will prohibit slurry from reaching storm drain inlets.
• Wash concrete trucks off site or in designated areas on site designed to preclude discharge of wash water to drainage system.

Further Practices for Preventing Contamination from Concrete Washout

Using Portland cement-containing products requires prevention of the discharge of high pH liquids to creeks, streams, and other water bodies, or in places where it might eventually reach creeks and streams. (xxii)

• Be aware of local environmental sensitivities around the job site. Know where streams and street drains are in order to avoid discharging harmful materials.
• Install continuous pH monitoring devices on effluent outflow. If the pH goes outside of the range of 6.5-9.0, have a means of treating the effluent prior to discharge.
• Grade the site to prevent storm runoff from leaving yard.
• Have an adequately-sized effluent pond.
• Have reliable means of testing pH on site and personnel trained in the measurement of pH (see How Can I Measure pH?).
• Wash chutes off in an area with permeable ground, and away from any subsurface drains (tile fields, perimeter drains, etc.), streams or storm drains. Although New Jersey DOT specifically states “Concrete truck washout onsite is prohibited outside designated areas. Designated washout areas shall be lined and bermed to prevent discharges to surface and ground water. Hardened concrete from concrete truck washout shall be removed and properly disposed of.” (xxiii)
• Have some means of containing the wash-water for disposal back at the plant if there is no appropriate place to wash the chute at the job site.
• Use equipment with wash water containment systems.

In the event that conditions at the work site change, a back-up plan is needed as the user should know ahead of time what to do if this happens. The following are practices to lessen the damage a spill of alkaline material might do to a fish-bearing waterway: (xxiv)
• Have on hand the names and telephone numbers of vacuum pumper truck companies that can come and clean out the catchbasins of street drains, or clean up material spilled on the ground (look in the Yellow Pages under “septic tanks - cleaning and removal”). Many DOTs and municipalities also have vacuum trucks.

• Have on hand some means of blocking storm drains or other potential routes to any water bodies.

• Have on hand some means of checking the pH of spilled material.

5.5 PAVEMENT MARKING

Work to replace and maintain roadway delineation typically includes refurbishing, delineation and replacement of missing markers. Environmental stewardship practices ensure that paints, debris and excess maintenance and repair materials remain controlled and are not released to the environment.

In September 1999, EPA redefined traffic paint into two categories, traffic marking coatings and zone marking coatings. Zone marking coatings are defined as those used on sidewalks, driveways, parking lots, curbs and airport runways and packaged in containers of five gallons or less, with Volatile Organic Compounds (VOCs) limited to 450 grams/liter or less; i.e. traditional oil-based traffic paint. Traffic marking coatings are now defined as those used for streets, highways and traffic areas as well as the purposes outlined for zone markings, with a VOC limit of 150 grams/liter. This means that traffic marking contractors must use low-VOC traffic paint when marking roadways, which in most cases will mean using latex traffic paint. In transitioning to latex traffic paint, DOTs have had to make sure that equipment is waterbase compatible, in order to avoid application and maintenance problems. Modifications have included use of stainless steel on critical wetted parts, with plated components being adequate in very few areas. New application techniques have also applied, especially for low-VOC alkyd paints which contain acetone, a product with a low flash point.

Practices for Specific Types of Pavement Marking

Paint Striping and Marking

Pavement striping is used for lane stripes and other pavement markings to guide motorists. Surfaces may be swept prior to painting. Water-based paints are applied using striper paint systems. Other pavement markings may be applied using striper paint systems or stencils. Potential pollutant sources such as overspray, dust, spills and leaks may create pollutants, including paint, sediment, fuel, hydraulic fluid and oil. Water used during presweeping operations should be controlled to prevent unpermitted non-stormwater discharges. Other recommended environmental stewardship practices include illicit connection/illicit discharge reporting and removal, scheduling and planning, illegal spill discharge control, spill prevention and control, safer alternative products, vehicle and equipment fueling, vehicle and equipment maintenance, solid waste management, liquid waste management, material use, sweeping and vacuuming and water conservation practices. (xxv)
Raised/Recessed Pavement Marker Application and Removal

Pavement markers supplement traffic signs. Markers may either be surface mounted (raised) or placed in recessed slots in the pavement. Markers are applied using bitumen/epoxy adhesives. Damaged markers are removed using hand tools or grinders and loaders. Potential pollutant sources such as excess application, spills and leaks may result in the release of potential pollutants of epoxy, fuel, hydraulic fluid and oil. Recommended environmental stewardship practices include illicit connection/illicit discharge reporting and removal, scheduling and planning, illegal spill discharge control, spill prevention and control, vehicle and equipment fueling, vehicle and equipment maintenance, solid waste management, and material use. (xxvi)

General Environmental Stewardship Practices for Pavement Marking

General environmental stewardship practices for pavement marking include the following: (xxvii)

- Schedule pavement marking activities for dry weather. Do not conduct painting or traffic marking activities during rain events.
- Replace solvent-based alkyd traffic paints with waterborne paints that contain 80 percent less organic solvents and with epoxy paints that release no solvent vapors.
- Develop paint handling procedures for proper use, storage, and disposal of paints.
- Transfer and load paint and hot thermoplastic away from storm drain inlets.
- Provide drop cloths and drip pans in paint mixing areas.
- Properly maintain application equipment.
- Street sweep thermoplastic grindings. Yellow thermoplastic grindings may require special handling as they may contain lead.
- Properly dispose of paints containing lead or tributyltin, which are considered a hazardous waste.
- Use water based paints whenever possible. If using water based paints, clean the application equipment in a sink that is connected to the sanitary sewer.
- Properly store leftover paints, if they are to be kept for the next job, or dispose of properly.

Removing Traffic Stripe and Pavement Marking

Waste from removal of yellow thermoplastic and yellow painted traffic stripe and pavement marking contains lead chromate in average concentrations greater than or equal to 350 mg/kg and less than 1000 mg/kg Total Lead. Residue produced when yellow thermoplastic and yellow paint are removed may contain heavy metals in concentrations that exceed established thresholds and may produce toxic fumes when heated. Waste from removal of yellow thermoplastic and yellow painted traffic stripe and pavement marking contains lead chromate in average concentrations greater than or equal to 5 mg/L Soluble Lead or 1000 mg/kg Total Lead. Caltrans has specified the following
environmental stewardship practices for removing traffic stripe and pavement marking:

- Removed yellow thermoplastic and yellow paint should be disposed of at a Class 1 disposal facility or a Class 2 disposal facility. Testing of residue is likely to require EPA’s Total Lead and Chromium Method 7000 series. If the yellow thermoplastic and yellow painted traffic stripe and pavement marking residue is transported to a Class 1 disposal facility, a manifest should be used, and the transporter should be registered with the California Department of Toxic Substance Control. The Engineer will obtain the United States Environmental Protection Agency Identification Number and sign all manifests as the generator within 2 working days of receiving sample test results and approving the test methods.

- The contractor should prepare a project specific Lead Compliance Plan to prevent or minimize worker exposure to lead while handling removed yellow thermoplastic and yellow paint residue. Personal protective equipment, training, and washing facilities required by the Contractor’s Lead Compliance Plan should be supplied by the Contractor.

- Prior to removing yellow thermoplastic and yellow painted traffic stripe and pavement marking, personnel who have no prior training, including State personnel, should complete a safety training program provided by the Contractor that meets state requirements.

- Where grinding or other methods approved by the Engineer are used to remove yellow thermoplastic and yellow painted traffic stripe and pavement marking, the removed residue, including dust, should be contained and collected immediately. Sweeping equipment should not be used. Collection should be by a high efficiency particulate air (HEPA) filter equipped vacuum attachment operated concurrently with the removal operations or other equally effective methods approved by the Engineer.

- The Contractor should submit a written work plan for the removal, storage, and disposal of yellow thermoplastic and yellow painted traffic stripe and pavement marking to the Engineer for approval.

- The removed yellow thermoplastic and yellow painted traffic stripe and pavement marking residue should be stored and labeled in covered containers, conforming to state provisions. The containers should be a type approved by the United States Department of Transportation for the transportation and temporary storage of the removed residue. The containers should be handled so that no spillage will occur. The containers should be stored in a secured enclosure at a location within the project limits until disposal, as approved by the Engineer.

5.6 CURB AND SIDEWALK REPAIR

Curb and sidewalk repair may include use of a compressor, jackhammer or sawcutting, curing, and the disposal of removed materials. Leaks, spills and concrete washout can
create result in release of pollutants such as fuel, hydraulic fluid, oil, sediment and concrete.

- Water applied during curing operations should be controlled to prevent unpermitted non-stormwater discharges.
- Other recommended environmental stewardship practices include illicit connection/illicit discharge reporting and removal, scheduling and planning, illegal spill discharge control, vehicle and equipment fueling, vehicle and equipment maintenance, solid waste management, hazardous waste management, liquid waste management, sanitary/septic waste management, concrete waste management, material use, safer alternative products, spill prevention and control, sweeping and vacuuming and water conservation practices. (xxix)

5.7 Recycling in Pavement and Roadside Appurtenances

Recycling in the Aggregate Industry and Pavement Construction

Recycled aggregate is usually defined as aggregates resulting from the reprocessing of mineral construction materials, mainly crushed concrete and asphalt. Recycling is a major area of growth in the aggregate industry. A number of European countries already have legal requirements, and in the United Kingdom (U.K.) the government has indicated that as much as 25 percent of construction aggregate demand should in the future be met from secondary and recycled sources. (xxx) Recycling in the aggregate industry and pavement construction is on the rise in the U.S. as well, as detailed in the individual sections below.

FHWA’s Recycled Materials Policy stresses recycling in pavement construction, stating that “[r]ecycling and reuse can offer engineering, economic and environmental benefits. Recycled materials should get first consideration in materials selection. Determination of the use of recycled materials should include an initial review of engineering and environmental suitability. An assessment of economic benefits should follow in the selection process. Restrictions that prohibit the use of recycled materials without technical basis should be removed from specifications.” (xxi) FHWA developed User Guidelines for Waste and Byproduct Materials in Pavement Construction, with guidelines are available for the following materials: (xxii)

- Baghouse Fines
- Blast Furnace Slag
- Coal Bottom Ash/Boiler Slag
- Coal Fly Ash
- FGD Scrubber Material
- Foundry Sand
- Kiln Duts
- Mineral Processing Wastes
- MSW Combustor Ash
• Nonferrous Slags
• Quarry Byproducts
• Reclaimed Asphalt Pavement
• Reclaimed Concrete Material
• Roofing Shingle Scrap
• Scrap Tires
• Sewage Sludge Ash
• Steel Slag
• Waste Glass

Furthermore, FHWA developed descriptions of the following applications: (xxxiii)
• Asphalt Concrete Pavement
• Portland Cement Concrete Pavement
• Granular Base Embankment or Fill
• Stabilized Base
• Flowable Fill

Table 1: Recycled Materials Applications – FHWA

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<thead>
<tr>
<th>Application/Use</th>
<th>Material</th>
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<tbody>
<tr>
<td>Asphalt Concrete – Aggregate (Hot Mix Asphalt)</td>
<td>Blast Furnace Slag</td>
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<td></td>
<td>Coal Bottom Ash</td>
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<td>Coal Boiler Slag</td>
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<td>Foundry Sand</td>
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<td>Mineral Processing Wastes</td>
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<td>Municipal Solid Waste Combustor Ash</td>
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<td>Nonferrous Slags</td>
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<td>Reclaimed Asphalt Pavement</td>
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<td>Roofing Shingle Scrap</td>
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<td>Scrap Tires</td>
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<td>Steel Slag</td>
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<td>Waste Glass</td>
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<tr>
<td>Asphalt Concrete – Aggregate (Cold Mix Asphalt)</td>
<td>Coal Bottom Ash</td>
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<td></td>
<td>Reclaimed Asphalt Pavement</td>
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<tr>
<td>Asphalt Concrete – Aggregate (Seal Coat or Surface Treatment)</td>
<td>Blast Furnace Slag</td>
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<td>Coal Boiler Slag</td>
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<td>Steel Slag</td>
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<tr>
<td>Asphalt Concrete – Mineral Filler</td>
<td>Baghouse Dust</td>
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<td></td>
<td>Sludge Ash</td>
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<td></td>
<td>Cement Kiln Dust</td>
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<td>Lime Kiln Dust</td>
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<td></td>
<td>Coal Fly Ash</td>
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<tr>
<td>Asphalt Concrete – Asphalt Cement Modifier</td>
<td>Roofing Shingle Scrap</td>
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<td></td>
<td>Scrap Tires</td>
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Chapter 5: Pavement, Materials, and Recycling
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<thead>
<tr>
<th><strong>Portland Cement Concrete – Aggregate</strong></th>
<th><strong>Reclaimed Concrete</strong></th>
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<tbody>
<tr>
<td><strong>Portland Cement Concrete – Supplementary Cementitious Materials</strong></td>
<td><strong>Coal Fly Ash</strong>&lt;br&gt;<strong>Blast Furnace Slag</strong></td>
</tr>
<tr>
<td><strong>Granular Base</strong></td>
<td><strong>Blast Furnace Slag</strong>&lt;br&gt;<strong>Coal Boiler Slag</strong>&lt;br&gt;<strong>Mineral Processing Wastes</strong>&lt;br&gt;<strong>Municipal Solid Waste Combustor Ash</strong>&lt;br&gt;<strong>Nonferrous Slags</strong>&lt;br&gt;<strong>Reclaimed Asphalt Pavement</strong>&lt;br&gt;<strong>Reclaimed Concrete</strong>&lt;br&gt;<strong>Steel Slag</strong>&lt;br&gt;<strong>Waste Glass</strong></td>
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<td><strong>Embankment or Fill</strong></td>
<td><strong>Coal Fly Ash</strong>&lt;br&gt;<strong>Mineral Processing Wastes</strong>&lt;br&gt;<strong>Nonferrous Slags</strong>&lt;br&gt;<strong>Reclaimed Asphalt Pavement</strong>&lt;br&gt;<strong>Reclaimed Concrete</strong>&lt;br&gt;<strong>Scrap Tires</strong></td>
</tr>
<tr>
<td><strong>Stabilized Base – Aggregate</strong></td>
<td><strong>Coal Bottom Ash</strong>&lt;br&gt;<strong>Coal Boiler Slag</strong></td>
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<tr>
<td><strong>Stabilized Base – Cementitious Materials</strong>&lt;br&gt;(Pozzolan, Pozzolan Activator, or Self-Cementing Material)</td>
<td><strong>Coal Fly Ash</strong>&lt;br&gt;<strong>Cement Kiln Dust</strong>&lt;br&gt;<strong>Lime Kiln Dust</strong>&lt;br&gt;<strong>Sulfate Wastes</strong></td>
</tr>
<tr>
<td><strong>Flowable Fill – Aggregate</strong></td>
<td><strong>Coal Fly Ash</strong>&lt;br&gt;<strong>Foundry Sand</strong>&lt;br&gt;<strong>Quarry Fines</strong></td>
</tr>
<tr>
<td><strong>Flowable Fill – Cementitious Material (Pozzolan, Pozzolan Activator, or Self-Cementing Material)</strong></td>
<td><strong>Coal Fly Ash</strong>&lt;br&gt;<strong>Cement Kiln Dust</strong>&lt;br&gt;<strong>Lime Kiln Dust</strong></td>
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The University of Texas Center for Transportation Research has also produced overviews of how recycled products can be used in several applications, including: (xxxiv)

- **Recycling In Concrete**
- **Recycling in Embankments**
- **Recycling in Roadbase**
- **Roadway Safety Devices**

FHWA has developed two NHI Courses on recycling as it pertains to pavement., **Portland Cement Concrete Pavement Evaluation and Rehabilitation (131062A)** (xxxv) and **Hot Mix Asphalt Pavement Evaluation and Rehabilitation (131063A)**.(xxxvi)
Reclaimed Asphalt Pavement (RAP)

Asphalt pavement is the nation’s most widely recycled product; twice as much asphalt pavement is recycled as paper, glass, plastic and aluminum combined.\(^{xxxvii}\) The Federal Highway Administration reports that 73 million metric tons of the 91 million metric tons (or 80.3 million of the 100.1 million tons) of asphalt pavement that is removed each year during resurfacing and widening projects is reused as part of new roads, roadbeds, shoulders and embankments, for a recycling rate of 80 percent. When a road is widened or resurfaced, the top layer of asphalt pavement is removed and later re-mixed with fresh materials. Hot Mix Asphalt provides a way not only to reuse old asphalt pavement but also to put other waste products to good use. Specifications for asphalt pavement now include such ingredients as rubber from old tires, slag from the steel-making process, sand from metal-casting foundries, and waste from the production of roofing shingles.\(^{xxxviii}\)

Although some form of pavement recycling was practiced as early as 1915, the first sustained efforts to recover and reuse old asphalt paving materials were conducted in the mid 1970s. With financial support of FHWA and technical assistance from trade associations such as the National Asphalt Pavement Association and the Asphalt Institute, more than 40 states placed demonstration reclaimed asphalt pavement (RAP) projects by 1982. RAP, is now routinely used in nearly all 50 states. FHWA estimates that nearly 30 million tons are recycled into hot-mix asphalt (HMA) pavements each year, saving taxpayers more than $300 million annually by reducing material and disposal costs.\(^{xxxix}\)

Asphalt and aggregate are non-renewable resources. Mining quality aggregate and opening new quarries has its problems. Often the roadway that needs to be rehabilitated may possess the best available aggregate. In addition to its environmental benefits, recycling provides a cheaper, faster and less disruptive alternative to conventional methods of reconstruction. It saves time during construction and time to the traveling public.\(^{xl}\)

Reclaimed asphalt pavement (RAP) is defined as salvaged, milled, pulverized, broken, or crushed asphalt pavement. It is removed or reprocessed from pavements undergoing reconstruction or resurfacing. Reclaiming the bituminous concrete may involve either cold milling a portion of the existing bituminous concrete pavement or full depth removal and crushing.\(^{xli}\) RAP is produced by crushing and screening the material to a \(\frac{1}{4}\) to \(\frac{1}{2}\) - inch in size. It is tested to ensure that the proper applicable gradation and quality is satisfied, and if so, the RAP is mixed with virgin aggregate and asphalt as needed, then placed. When properly crushed and screened, RAP consists of high-quality, well-graded aggregates coated by asphalt cement. Since millings from different projects will have different characteristics, contractors must maintain separate stockpiles of milled material, and the properties of particular stockpiles will change as it used and reused. \(^{xlii}\)

Although the majority of old asphalt pavements are recycled at central processing plants, asphalt pavements may be pulverized in place and incorporated into granular or stabilized base courses using a self-propelled pulverizing machine. Hot in-place and cold in-place recycling processes have evolved into continuous train operations that include partial depth removal of the pavement surface, mixing the reclaimed material with beneficiating additives (such as virgin aggregate, binder, and/or softening or rejuvenating agents to
improve binder properties), and placing and compacting the resultant mix in a single pass.\textsuperscript{xliii}

RAP properties largely depend on its existing in-place components. There can be significant variability among existing in-place mixes depending on type of mix, and in turn, aggregate quality and size, mix consistency, and asphalt content. Due to traffic loading and method of processing, RAP is finer than its original aggregate constituents are; it is finest when milled.\textsuperscript{xliv}

Reflection cracking induced by environmental or traffic loads, and/or a combination of the two is a principal form of distress in hot mix asphalt (HMA) overlays of resurfaced flexible and rigid pavements. When these cracks propagate through the AC overlay, infiltration of water and de-icing salts can cause rapid deterioration of the underlying pavement structure and foundation. The basic mechanisms leading to the development of reflection cracking are horizontal and differential vertical movements between the original pavement and HMA overlay.

Recent work performed under NCHRP Project 1-37A, \textit{Development of the 2002 Guide for the Design of New and Rehabilitated Pavement Structures: Phase II}, found that the severity of reflection cracks (transverse and longitudinal) significantly affects ride quality as measured by the International Roughness Index (IRI). In 2005, NCHRP will oversee research to identify the most appropriate mechanistic-based model for reflective cracking in AC overlays and calibrate, validate, and incorporate that model into the framework and procedure (software) being developed under NCHRP Project 1-37A. Traffic levels, overlay thickness, environments and “foundation” types (e.g., old PCC, stabilized base, and old AC) will be examined.\textsuperscript{xlv}

FHWA’s Turner Fairbanks Research Center makes the following recommendations for use of milled or crushed RAP in a number of highway construction applications, including as an aggregate substitute and asphalt cement supplement in recycled asphalt paving (hot mix or cold mix), as a granular base or subbase, stabilized base aggregate, or as an embankment or fill material: \textsuperscript{xlvi}

\textbf{Example 1: Uses of Recycled Asphalt Pavement}

\textbf{Asphalt Concrete Aggregate and Asphalt Cement Supplement}

Recycled asphalt pavement can be used as an aggregate substitute material, but in this application it also provides additional asphalt cement binder, thereby reducing the demand for asphalt cement in new or recycled asphalt mixes containing RAP. When used in asphalt paving applications (hot mix or cold mix), RAP can be processed at either a central processing facility or on the job site (in-place processing). Introduction of RAP into asphalt paving mixtures is accomplished by either hot or cold recycling.

\textbf{Hot Mix Asphalt (Central Processing Facility)}

Recycled hot mix is normally produced at a central RAP processing facility, which usually contains crushers, screening units, conveyors, and stackers designed to produce and stockpile a finished granular RAP product processed to the desired gradation. This product is subsequently incorporated into hot mix asphalt paving mixtures as an aggregate substitute. Both batch plants and drum-mix plants can incorporate RAP into hot mix asphalt.

\textbf{Hot Mix Asphalt (In-Place Recycling)}

Hot in-place recycling is a process of repaving that is performed as either a single or multiple pass operation using specialized heating, scarifying, rejuvenating, laydown, and compaction equipment. There is no processing required prior to the actual recycling operation.
Cold Mix Asphalt (Central Processing Facility)
The RAP processing requirements for cold mix recycling are similar to those for recycled hot mix, except that the graded RAP product is incorporated into cold mix asphalt paving mixtures as an aggregate substitute.

Cold Mix Asphalt (In-Place Recycling)
The cold in-place recycling process involves specialized plants or processing trains, whereby the existing pavement surface is milled to a depth of up to 150 mm (6 in), processed, mixed with asphalt emulsion (or foamed asphalt), and placed and compacted in a single pass. CIR is suitable for roadways with moderate to severe distresses where reflection cracking is a concern. CIR involves milling the existing pavement, screening for oversize, addition of asphalt emulsion, and mixing; then this cold renewed material is spread, reprofiled, and compacted on the roadway in one continuous operation. There is no processing required prior to the actual recycling operation.

Granular Base Aggregate
To produce a granular base or subbase aggregate, RAP must be crushed, screened, and blended with conventional granular aggregate, or sometimes reclaimed concrete material. Blending granular RAP with suitable materials is necessary to attain the bearing strengths needed for most load-bearing unbound granular applications. RAP by itself may exhibit a somewhat lower bearing capacity than conventional granular aggregate bases.

Stabilized Base Aggregate
To produce a stabilized base or subbase aggregate, RAP must also be crushed and screened, then blended with one or more stabilization reagents so that the blended material, when compacted, will gain strength.

Embankment or Fill
Stockpiled RAP material may also be used as a granular fill or base for embankment or backfill construction, although such an application is not widely used and does not represent the highest or most suitable use for the RAP. The use of RAP as an embankment base may be a practical alternative for material that has been stockpiled for a considerable time period, or may be commingled from several different project sources. Use as an embankment base or fill material within the same right-of-way may also be a suitable alternative to the disposal of excess asphalt concrete that is generated on a particular highway project.

Practices in Use of RAP
The University of Texas at Austin’s Center for Transportation Research (CTR) conducted study 7-2918, Production Variability Analysis of Hot-Mixed Asphalt Concrete (HMAC) Containing RAP, evaluated the production and construction variability of HMAC containing high quantities of RAP material and recommended the following practices to effectively use this recycled resource: (xlvii)

- When the RAP material is used, the gradation of the RAP should be determined using a procedure that results in an aggregate gradation similar to what is obtained during the milling operation. RAP aggregate gradation from road cores can differ significantly from RAP aggregate gradation obtained from milling, the latter being finer owing to the crushing action of the milling machine. The mix design gradation based on road cores may not be representative of the actual gradation during construction.

- The use of a high percentage of RAP should be restricted until means are available to reduce the mix variability when a high quantity of RAP is used, or until sufficient evidence exists that further deviations from the target values can be allowed without adversely influencing the pavement performance.

Florida DOT studies to develop specifications for using RAP as base, subbase or general fill materials found that an 80 percent RAP-20 percent soil mix produced the most desirable engineering behavior and that RAP poses no environmental concerns when used as a highway material. The concentrations of heavy metals were well below the
EPA standards after samples were taken over a 12-month period and subjected to four different environmental testing procedures.\textsuperscript{xlvi}

The Joint Task Force #38 on CIR (AASHTO/AGC/ARTBA) voted and approved specifications for Cold In-place Recycling (CIR), for which the University of New Hampshire (UNH) in conjunction with University of Rhode Island (URI) was commissioned to develop a performance based mix design. Joint Task Force #40 on Hot In-place Recycling (HIR) is underway, and a proposed Joint Task Force for Full Depth Reclamation was submitted by Asphalt Recycling and Reclaiming Association (ARRA) for consideration. NCHRP Project 1-37A, due in 2004, is developing a new \textit{Guide for Design of New and Rehabilitated Pavement Structures}, accompanied by the necessary computational software, for adoption and distribution by AASHTO. The new guide will contain procedures for the design and analysis of all types of new and rehabilitated pavement systems (e.g., flexible, rigid, and semi-rigid pavements) and is expected to provide many improvements over current pavement design procedures. The Guide will emphasize rehabilitation design, since approximately 73 percent of the Nation’s pavement design dollars are spent on rehabilitation. The Guide will include procedures for evaluating existing pavements; recommendations on rehabilitation treatments; procedures for life cycle cost analysis and reliability; procedures for calibrating for local conditions; and ways to reduce life cycle costs and make better use of available materials.

\textbf{Use of RAP in Superpave}

Originally the Strategic Highway Research Program, Superpave (\textit{SUperior PERforming Asphalt PAVEments}) did not provide guidelines for the inclusion of RAP. However, agency and industry personnel, as well as researchers, seem to agree that as long as RAP is treated as an engineered construction material and the unique properties of the RAP are known. Recently completed research, conducted under the auspices of the National Cooperative Highway Research Program (NCHRP), the North Central Superpave Center, and the Asphalt Institute confirms that Superpave can easily and effectively accommodate the use of RAP. The overall Superpave mix design process with RAP is very similar to that described in AASHTO MP2. Although RAP is treated like any other stockpile for blending and weighing, the following practices are required:

- The RAP must be heated gently to avoid changing the RAP binder properties.
- The RAP aggregate specific gravity must be estimated.
- The weight of the binder in the RAP must be accounted for when batching aggregates, and the total asphalt content reduced to compensate for the RAP binder.
- The virgin binder grade may need to be changed depending upon the RAP percentage and binder grade and the desired blend. Though not Superpave-specific, other factors to consider when using RAP are those related to production and quality control testing.
- Higher plant temperatures are necessary if the ambient temperature is low or the moisture content of the materials is high. Greater energy consumption may affect plant production.
• Stricter stockpile management and more frequent sampling and testing of the RAP may be necessary to ensure consistency and quality.

As described in NCHRP Research Results Digest 253, the findings of the NCHRP Project 9-12 research effort largely confirmed current practice and supported the use of blending charts. The report, “Incorporation of Reclaimed Asphalt Pavement in the Superpave System”, promotes a tiered approach to the use of RAP. Low amounts of RAP, typically 10-20 percent, can be used without testing the recovered binder. With higher RAP contents, Superpave binder tests can be used to determine how much RAP may be added or which virgin PG binder is needed. Conventional Superpave binder tests can be used to determine how much RAP can be added or which virgin binder to use when higher RAP contents are desired.(xl ix)

• The properties of the aggregate in the RAP may limit the amount of RAP that can be used and should be considered as the RAP comprises another aggregate stockpile. It may be presumed that the mixtures being recycled met specifications and certain minimum aggregate properties and mixture properties when constructed; however, such specs differ from those of Superpave.

• RAP aggregates should be blended with virgin aggregates, so the blend meets the consensus properties.

• In the mix design, the RAP binder should be taken into account, and the amount of virgin binder added should be reduced accordingly. DSR and bending beam rheometer (BBR) tests may replace the viscosity tests that were previously used, but the concepts are still the same.

The authors concluded that such practices are already widely utilized, the research effort should give agencies confidence in extending the use of RAP to Superpave mixtures.(l) Illinois DOT is among the state DOTs that allow incorporation of RAP into Superpave mixes. As of 2000, the amount of RAP allowed for low volume roads increased from 25 percent to 30 percent. For some non-critical mixes, such as the shoulder, base, and subbase, up to 50 percent RAP is allowed. For high-type binder courses, up to 25 percent is allowed. For surface courses, the amount allowed ranges from 10 percent to 15 percent for all but the highest volume highways. RAP is not allowed in the Department’s highest-class bituminous concrete surface or polymer-modified mixes to maintain acceptable friction requirements. The Department also allows RAP to be used in place of aggregate or earth in some non-structural backfill situations. Recently, RAP has been used in 40 to 60 percent of the Department’s most common surface and base course mixes, and over 60 percent of total shoulder mix tonnage; 623,000 tons were used in 2001. (li)(lii) The Illinois DOT used about 623,000 tons of RAP in 2001 as a viable aggregate substitute for scarce bituminous resources.(liii)

A regional pooled fund project was recently conducted to investigate the performance of Superpave asphalt mixtures incorporating RAP to determine if findings of NCHRP 9-12 (Incorporation of Reclaimed Asphalt Pavement in the Superpave System) were valid for Midwestern materials and to expand the NCHRP findings to include higher RAP contents. Mixtures were designed and tested in the laboratory with RAP materials from Indiana, Michigan and Missouri, virgin binder and virgin aggregate at RAP contents up to 50 percent.
• The results showed that mixtures with up to 50 percent RAP can be designed under Superpave, provided the RAP gradation and aggregate quality were sufficient. In some cases, the RAP aggregates limited the amount of RAP that could be included in a new mix design to meet the Superpave volumetric and compaction requirements. Linear binder blending charts were found to be appropriate in most cases.

• In general, increasing the RAP content of a mixture increased its stiffness and decreased its shear strain, indicating increased resistance to rutting.

• Best practices require consideration of the RAP aggregate gradation and quality in the mix design, since a poor aggregate structure could reduce mixture stiffness and ultimately performance.

The study showed that provided the RAP properties are properly accounted for in the material selection and mix design process, Superpave mixtures with RAP can perform very well.(liv)

The Asphalt Recycling & Reclaiming Association (ARRA) recently spent two years producing the Basic Asphalt Recycling Manual (BARM) endorsed by FHWA. The BARM introduces road managers to the recycling technologies that are available today; six different disciplines that can effectively recycle and rejuvenate those deteriorated asphalt pavements. Dry planning, hot plant, hot in-place recycling, cold in-place recycling, full-depth reclaiming and soil stabilization can address a range of problems associated with asphalt pavements and base soils. The BARM covers each discipline from historic information, pavement assessment, structural capacity, material properties, geometric, traffic, economic and environmental assessments. It also provides mix design, blending charts, method specifications, end results specifications, inspection, quality control and quality assurance.

In-Situ Hot Mixes: Cold In-Place Recycling and Hot In-Place Recycling

Hot in-place recycling (HIR) is a process of repaving that is performed as either a single or multiple pass operation using specialized heating, scarifying, rejuvenating, laydown, and compaction equipment. Cold in-place recycling (CIR) process involves specialized plants or processing trains, whereby the existing pavement surface is milled to a depth of up to 150 mm (6 in), processed, mixed with asphalt emulsion (or foamed asphalt), and placed and compacted in a single pass. Neither process requires processing prior to the actual recycling operation.

Joint Task Force #38 on CIR (AASHTO/AGC/ARTBA) voted and approved specifications for Cold In-place Recycling (CIR), for which the University of New Hampshire (UNH) in conjunction with University of Rhode Island (URI) was commissioned to develop a performance based mix design. Joint Task Force #40 on Hot In-place Recycling (HIR) is underway, and a proposed Joint Task Force for Full Depth Reclamation was submitted by Asphalt Recycling and Reclaiming Association (ARRA) for consideration.

Cold In-Place Recycling

Cold in-place recycling, which is essentially total reconstruction of a road, encounters few cost-prohibitive problems. Material costs are less because the existing material is
recycled and reused. Though many times aggregate or asphalt must be added to create a proper base, this is much more cost-effective than removing the road bed. Additionally, the material is recycled “in-place,” meaning there is little need for excavation or hauling. In the end, cold in-place recycling costs anywhere from one-third to one-half of the total cost incurred for conventional reconstruction. Furthermore, when done properly cold in-place recycling can offer better results than conventional reconstruction. Reasons that CIR is not more common include the perception that it only involves the road’s top layer of asphalt; however, cold in-place recycling is total reconstruction of a road because the process goes down to the subgrade. Additives have also been a point of debate, though the recycling process itself should not be jeopardized by choices of wrong additives or dilution. 

In-place recycling has played a large role in pavement maintenance strategies in some states. In a shift to a more pro-active road maintenance strategy, Nevada DOT is prioritizing projects based on how quickly roads are deteriorating or prediction models, not on the basis of their current condition. Prevention strategies are ranked by life-cycle cost, not initial cost. The program required initial larger expenditures on pavement preservation, to reduce its backlog. NDOT deployed cold-in-place recycling based on a sophisticated lifecycle cost comparison; the state optimized its projects by assigning roads to five categories based on volume and environmental conditions. Cold-in-place recycling provided a pavement performance life comparable to that of overlays. Cold in-place recycling was adapted for harsher winter conditions in Nevada by adjusting the lime added to the mix. 

The Montana Department of Transportation (MDT) turned to CIR to deal with has dealt with road maintenance needs, insufficient maintenance funds, challenges in siting new quarries and asphalt plants, diminishing supplies of virgin aggregates, expensive freight costs for paving remote locations, and environmental concerns. MDT found that CIR produces less thermal and reflective cracking than HIR in Montana, and that CIR can be used to remove thermal and reflective cracks, maintain clearances, improve poor aggregate gradations, reuse existing materials and minimize the need for new materials, as well as strengthen the pavement. MDT’s process combines a defined sampling protocol, an engineered design protocol with performance-related testing of laboratory prepared samples, quicker field compaction and construction specifications and a new chemistry (ReFlex) emulsion. The new chemistry allows a better coating and higher asphalt content than conventional CIR. The performance-related specifications include tests for low-temperature cracking, raveling, strength and stripping resistance. The specifications also include requirements for the construction equipment and practices, as well as quality control and quality assurance.

**Hot In-Place Recycling**

HIR is considered a maintenance technique because HIR is a shallow-depth treatment used to rehabilitate road surfaces with minor deficiencies in the upper 1 to 2 inches of existing asphalt pavement before major distresses appear. There are three different types of HIR processes, each with its own benefits and best applications, but generally hot-in-place recycling is used by agencies as an alternative to milling 2 inches of pavement and laying down 2 inches of new hot-mix asphalt. The HIR processes have the advantages of being inexpensive, relatively fast, and adding substantial life to the original pavement.
Advances in technology and techniques in the 90s made hot-in-place recycling an increasingly popular and cost-effective pavement maintenance technique. Contractors now heat the pavement more gradually, using multiple pre-heaters operating at lower temperatures to gently bring the pavement up to scarifying temperatures. A much higher quality recycled mix results, with minimal vapors produced by the process. Better emissions systems incinerate fumes, reducing them to carbon dioxide and water. The following overview of the three main HIR processes is from K. Lander’s “Recycling as a Life-Extending Maintenance Tactic,” in *Better Roads*, July 2002.

**Surface Recycling**

Surface recycling is the most basic type of hot-in-place recycling. It is used for scarifying depths of 0.75 to 1.5 inches, with a depth of one inch being most common. The treatment can be used to rejuvenate the asphalt binder in the existing pavement, to eliminate surface irregularities, and to create a uniform grade line and cross section to the pavement surface.

In surface recycling, two or three pre-heating units are followed by a heating/scarifying unit which provides final heating and loosens the asphalt. Augers mix the scarified asphalt with the recycling agent, which is metered into the mix by means of a computer controlled injection system. The mix is leveled and spread by a free-floating screed or a modified asphalt paver; heated, vibrating screeds are usually used to provide initial compaction. Traditional hot-mix asphalt compaction follows: breakdown rolling, usually with a pneumatic compactor, then a double-drum vibratory steel wheel roller. Static steel-wheel rollers are sometimes used for finish rolling. Because the existing asphalt pavement below the recycled mix is warm, a thermal bond develops between the two layers and there is ample time for compaction rolling. When the recycled mix cools, the road can be opened to traffic.

Surface recycling is usually followed with a surface treatment or a thin hot-mix asphalt lift. Without a surface treatment, the pavement’s service life probably ranges between two and four years; with a surface treatment, service life expectancies range from five or six years with a chip seal to ten years with a two-inch asphalt overlay.

Surface recycling is especially well suited to preparing pavements in rural areas, far removed from established HMA plant locations, for overlays. In such applications, the recycling crew creates a leveling course for the overlay, opening lanes for traffic as they go. This flexibility makes it possible to hold off bringing in the paving crew and its portable HMA plant until the entire leveling course has been completed. Thus, when the final lift is put down, both the paving crew and the hot-mix plant can work at maximum production rates — rather than having to adjust production to the pace of an HIR train or milling machine — saving time and money.

According to the Asphalt Recycling and Reclaiming Association’s Basic Asphalt Recycling Manual, surface recycling is most effective in addressing pavement raveling and improving ride quality. It can also be effective in treating pavements suffering from minor degrees of potholes, bleeding, rutting, corrugations, shoving, cracking, and other surface imperfections. It is not an effective solution for problems with skid resistance, shoulder drop off, fatigue cracking, edge cracking, discontinuity cracking or pavement strength.
Remixing

Remixing is the hot-in-place recycling technique that provides the most options for pavement remediation. It is considered a very cost effective solution to rutting, raveling, oxidation, and other flaws in the upper two inches of a pavement. Recycled asphalt modifications that are possible with remixing include aggregate gradation, abrasion/friction number enhancement, asphalt binder content, asphalt binder rheology, mix stability, and mix void properties.

In this process, preheaters and a heater/scarifying machine heat the pavement to depths of 1.5 to 2 inches, scarify it into windrows, then convey it to an on-board mixer. In the mixing chamber, the recycled mix is combined with any combination of modifiers, including recycling agents, admix, or virgin HMA. The modified mix is then placed with a full-floating screed or modified asphalt paver. The screeds are usually heated, with vibratory or tamping bar designs for initial compaction and with automatic grade and slope control.

As with the other HIR processes, remixing produces a heating bond between layers of asphalt. The underlying pavement is usually between 120-180 degrees F; and the recycled mix is between 230-265 F when the mix is placed. In addition, the heating units usually warm the pavement 4 to 6 inches beyond the scarification width, providing a thermally integrated bond between the recycled mix and the adjacent material.

Proponents of HIR say this creates a seamless longitudinal joint that resists environmental and traffic degradation. Compaction is the same as for surface recycling. Single-stage remixing — where the full depth of pavement is scarified in one operation — usually treats depths of 1 to 2 inches of pavement, with 1.5 inches the most common depth. This process was developed in Europe and Japan in the late 1970s and is widely used throughout the world.

Multiple stage remixing was developed in North America in the late 1980s and early 1990s as a way to achieve greater treatment depths with HIR. In this variation, the pavement is sequentially heated, softened, and scarified in layers, usually two to four layers. This process is used for remixing depths of 1.5 to 3.0 inches, with 2 inches being the most common.

Remixing can produce a wear-course-quality pavement with a service life of 7 to 14 years, depending on the quality of the original pavement and the admix and binder modifiers used. That makes remixing an effective option for road repairs that cannot add elevation to the original roadway whether it’s because of clearance problems or because repairs are needed on just one lane of a 2-lane road.

Remixing can also produce a leveling-course-quality pavement designed for a hot-mix asphalt overlay. The life expectancy for these applications is usually the life expectancy of the wear course — between 7 and 15 years, as a rule.

According to the Asphalt Recycling and Reclaiming Association’s Basic Asphalt Recycling Manual, remixing is most effective for treating pavements with potholes, bleeding, corrugations, shoving, or ride quality problems, as well as the fore-mentioned rutting, raveling, and oxidation, when these conditions are confined to the top two inches or so of the pavement. It can also be effective in treating a variety of cracks, surface irregularities, and skid-resistance deficiencies. It is not considered an effective treatment for shoulder drop-off problems, discontinuity cracking, or inadequate pavement strength, nor is it recommended for pavements with distresses that are more than two inches deep.
**Repaving**

Repaving combines the remixing process with the placement of an integral hot-mix asphalt overlay, with both layers compacted simultaneously. Repaving is used when surface recycling or remixing alone cannot restore the pavement profile or surface requirements such as friction number. Because it makes possible the use of a very thin HMA wear course layer, it is also used when a conventional HMA overlay isn’t practical. And repaving is used when pavement strengthening is needed; remixing can add up to 0.75 inches of pavement strengthening, while repaving can add up to 2 inches of strengthening.

In single-pass repaving, the last unit in the HIR train uses one screed to place the recycled mix and a second to place the HMA mix; both layers are then compacted as one. In the multiple-pass method, the last unit in the train has a single screed that places the recycled mix while a conventional HMA paver follows immediately behind to place and screed the virgin hot-mix asphalt layer on the recycled mix; both layers are compacted as one. Repaving treatments usually involve a recycled depth of 1 to 2 inches and an overlay of 1 to 2 inches; the typical combined thickness is three inches or less. Combined thickness of 4 inches or more can present difficulties in placement, compaction, and smoothness. Because of the thermal bonding between layers very thin HMA overlays are possible with this technique — as thin as 0.5 inches if the appropriate HMA mix is specified. With conventional overlays using two to three times as much hot-mix asphalt, thin-layer repaving is often less expensive than other hot-in-place recycling options that involve an overlay.

More typically, repaving specialists are recycling one inch of old pavement and adding a one-inch overlay in competition with a conventional two-inch mill-and-fill. Repaving has also proven to be well suited to municipal applications. Though the repaving train is slower than a milling machine and a paver in a mill and fill operation, it only interrupts traffic once and may displace traffic for less total time than a mill and fill solution. On an even more practical level, advocates point out that the repaving train only blocks access to any given parking lot or driveway for 10 or 15 minutes, and it leaves behind a road ready to use.

Re-paving does not require a tack coat between the leveling course and the wearing course. This is a plus because it eliminates the spread of the tar-like substance to parking lots, car panels, and shoes. Because of the relatively small volumes of HMA placed daily in repaving, the process is most practical for projects that are located within efficient hauling distances of established HMA plants.

According to the Asphalt Recycling and Reclaiming Association’s Basic Asphalt Recycling Manual, repaving is most effective in treating raveling, potholes, many types of cracking, or deficiencies in skid resistance or ride quality. It can be effective in treating bleeding, rutting, corrugations, shoving, and other surface imperfections. It can also be used to increase pavement strength.

Hot-in-place recycling is widely used in its various forms throughout the United States and Canada, though there are major concentrations of usage in areas where specialty contractors are based. Colorado’s Department of Transportation is one of the most prolific and experienced users of the remixing form of HIR; CDOT Region 5 reports crack elimination, excellent smoothness, and five to 10 years of service from this process in a tough mountain region when it is capped with a 2-inch overlay. Smoothness is also a
benefit the Texas Department of Transportation touts for its use of the HIR repaving process in metropolitan areas. In 2000, the department’s Houston District awarded three major HIR repaving projects totaling nearly 600,000 square yards. The largest of those projects, a heavily traveled, seven-lane arterial highway reported in the September 2001 issue of Better Roads, qualified for 85 percent of the contract’s smoothness bonus. Repaving also eliminated complaints about tack coat used in conventional overlays being tracked into businesses and cars. Driveways and intersections were blocked for no more than 15 minutes.\(^{(lvii)}\)

**Recycling with Foamed Asphalt**

In situ hot-mix recycling, including hot in-place recycling (HIR) and cold in-place recycling (CIR) has proved to be an economical rehabilitation technique that conserves granular materials and energy and results in zero waste.\(^{(lviii)}\) An increasingly popular version of in-place recycling uses foamed asphalt. “Foamed” or “expanded” asphalt is a road base recycling process in which pulverized pavement is mixed with an asphalt froth to create a stabilized road base. The expanded asphalt forms a mortar or glue that bonds particles. The technology sidesteps several aspects of conventional asphalt such as the use of solvents and the time waiting for the break for emulsions. Reclaimed asphalt pavement is often unusable as a new asphalt concrete mix or cold in-place recycled mixture because it is not uniform or the underlying pavement does not provide adequate structural support. Construction of a base with full depth reclamation (FDR) materials stabilized with foamed asphalt can solve the support problem. Result of studies by the Iowa and Kansas DOTs indicated that the foamed asphalt stabilized FDR material is a uniform material that can be placed and compacted easily, and that it can be efficiently used as base material in flexible pavements.\(^{(lix)}\)

Foamed asphalt is formed by carefully injecting a predetermined amount of cold water into hot penetration-grade asphalt in the mixing chamber of a pavement remixing unit. There, air bubbles in the expanded liquid asphalt froth act as the carriers of liquid asphalt to fines in a reclaimed asphalt pavement aggregate mix. While expanded asphalt doesn’t completely coat all aggregate surfaces, it does form a mortar or glue which bonds the particles together. In less than 15 seconds, the froth subsides and the dispersion of asphalt is achieved, eliminating time waiting for the “break” required when expensive asphalt emulsions are used. The technology also sidesteps use of costly cutback solvents. The liquid asphalt cement is pure, with nothing added to it to change its properties. That makes it more economical and environmentally viable than emulsions comprised of processed oil.

Louisiana is among the transportation agencies that have investigated and found great potential in the use of FA-treated RAP as a base course material in lieu of a crushed-limestone base beneath a concrete pavement layer.\(^{(lx)}\) Caltrans has experimented with foamed or expanded asphalt used along with in-place base recycling, largely because conventional reconstruction adds limited life but cold foaming gives another 10 years of operability. Closure times have also factored into the calculus; the cost of conventional reconstruction—months-long closure, excavation, trucks out with old pavement and base, trucks in with new base and pavement materials, and a parade of construction equipment—made reconstruction prohibitively expensive on a number of highways given their remote location, the few vehicles per day they served, and water-logged
environments. Foamed asphalt stabilization requires a mix design using actual materials from the job site to be developed prior to construction, which can be accomplished in a portable lab. With Caltrans, the cold-foamed asphalt process took about four working days to rebuild from bottom-up at a depth of 6 inches. A chip seal coating was added, so the road was effectively rebuilt in six days whereas conventional treatments would have taken 30-60 days. Caltrans is currently evaluating the cold foam under various extreme climatic conditions.\(^{(lxvi)}\)

Ulster County in New York’s Catskills has also begun to utilize the process to avoid weeks-long truck traffic, demolition material and virgin aggregate hauling, noise, dust and commotion, and to create a virtually new, high-performance road base at a fraction of the cost of new base materials and deep lifts of asphalt pavements. In-place recycling with foamed asphalt allows the County to reconstruct more roads each season in addition to the documented benefits of greater pavement resistance to penetration of water and rapid strength gain allowing traffic to resume as soon as compaction is complete. Additional water is not added to the recycled material, as is necessary when emulsion is used. The surface also accommodates excessive heaving caused by major expansion of clay road bases.\(^{(lxii)}\)

The Recycled Materials Resource Center produced a study on the use of foamed asphalt as a stabilizing agent, outlining the steps involved to design a foamed asphalt mix, construction of the foamed asphalt sections, and a preliminary evaluation of the application in Maine. The authors found that during the mix design process, the use of the foamed asphalt laboratory equipment is important to optimizing the design as proper asphalt-water ratios are determined to maximize performance. Preliminary evaluation using Falling Weight Deflectometer data revealed the structural capacity of foamed asphalt sections are greater than pical full depth reclamation sections. Long term evaluation of performance is planned.\(^{(lxiii)}\)

**Recycled Concrete Material/Aggregate (RCM/RCA)**

Recycling is a major part of the concrete industry, which is exploring environmental practices such as recycling of wastes as raw material and fuel for cement manufacturing; development of environmentally compatible cement (Ecocement) using wastes; environmental load-reducing cement emitting less carbon dioxide and NOx during manufacturing; up-grading of the performance of concrete aiming at energy-, resources-, and manpower-savings; utilization of wastes for concrete raw materials; and recycling of concrete wastes from obsolete concrete structures.\(^{(lxiv)}\)

Recycled Concrete Material (RCM) or Recycled Concrete Aggregate (RCA), also known as crushed concrete, is reclaimed PCC pavement material. Primary sources of RCM are demolition of existing concrete pavement, bridge structures, curb and gutter, and from central recyclers, who obtain raw feed from commercial/private facilities. This material is crushed by mechanical means into manageable fragments and stockpiled. RCM may include small percentages of subbase soil and related debris. The excavated concrete that will be recycled is typically hauled to a central facility for stockpiling and processing or, in some cases (such as large reconstruction projects), processed on site using a mobile plant. At the central processing facility, crushing, screening, and ferrous metal recovery operations occur. Present crushing systems, with magnetic separators, are capable of removing reinforcing steel without much difficulty. Welded wire mesh reinforcement,
however, may be difficult or impossible to remove effectively. To avoid inadvertent segregation of particle sizes, coarse and fine RCM aggregates are typically stockpiled separately. RCM is rougher and more absorbent than its virgin constituents. Furthermore, differences among concrete mixes and uses result in varying aggregate qualities and sizes; for example, pre-cast concrete is less variable than cast-in-place. (lxv) The use of RCM as an aggregate substitute in pavement construction is well established, and includes use in granular and stabilized base, engineered fill, and Portland cement concrete pavement applications. Other potential applications include its use as an aggregate in flowable fill, hot mix asphalt concrete, and surface treatments. To be used as an aggregate, RCM must be processed to remove as much foreign debris and reinforcing steel as possible.

Concrete pavements can be inexpensively repaired and restored with proper equipment, materials and procedures, and when concrete pavement restoration methods are no longer viable concrete overlays can add structural capacity and returning pavements to a smoother, safer condition. Concrete overlays include bonded, unbonded, whitetopping and ultra-thin whitetopping. AASHTO published a guide in 2001 on the use of fiber reinforcement in concrete transportation infrastructure and overlays. The resource includes general information on fibers, as well as guidance on proportioning, mixing and placing fiber-reinforced concrete. Typical applications of fiber-reinforced concrete also are discussed. The report can be obtained from AASHTO at www.transportation.org, publication code TF36-1.(lxvi)

State DOT Experiences with RCA

FHWA has research in progress on state DOT experiences with RCA, which are summarized in this section.(lxvii) In response to a survey by FHWA, 11 state DOTs said they used RCA in PCC.(lxviii) A much higher number, 38 DOTs, said they used RCA in aggregate base. Seventeen states use RCA in miscellaneous areas and applications. A graphic display of these states and uses is available at FHWA’s RCA website.(lxix) Minnesota, Utah, Virginia, Texas, and Michigan were chosen for an in-depth review of their recycled concrete aggregate program because of their experience with recycling concrete aggregate.

FHWA’s study also identified the following research needs where DOTs and industry suppliers are still looking to gain additional experience or information:

- Development of performance curves for concrete made with recycled aggregate.
- Development of database for RCA final product performance.
- Development of appropriate test procedures for specifying final products made with RCA.
- Development of a performance based specification for RCA.
- Research related to:
  - Minimize reflective cracking in pavements built over thick RCA base due to increased base stiffness.
  - Understand of recycled aggregate products; how they are affected in terms of strength, constructability, and long-term performance.
Incorporate RCA affected by D-cracking and ASR and in what proportions.
- Effect on product made with recycled aggregate affected by alkali silica reaction.
- Shrinkage effect on product made with recycled aggregate.

**Texas DOT (TxDOT)**

TxDOT is a large user of RCA materials, though private industry and municipalities consume over 60 percent of the RCA currently produced in Texas. Initially, there was a general perception that RCA is a waste product and thus substandard material. TxDOT has used RCA where the risk is minimal and with a high potential for performance. The use of RCA in new concrete also initially created problems with mix workability due to problems with the absorbency of the aggregate and the difficulty maintaining a consistent and uniform saturated surface dry condition of RCA aggregate. This hurdle was overcome by the contractor through their process control program, which heightened awareness of the need to water stockpiles and to conduct more frequent testing of aggregate for moisture content. Due to compressive strength and workability issues, TxDOT determined that 20 percent was the maximum amount of RCA fines that would be allowed in the concrete.

TxDOT has also performed training and continually present information to their Districts concerning the performance of the projects they have completed around the state. Through research, implementation, and competition, TxDOT has found that using RCA, like many other recycled materials, provides engineering, economic, and environmental benefits.

- RCA in new concrete decreases the resilient modulus and increases the creep, changes which are benefits in specific applications. TxDOT does not currently use RCA in structural concrete because of the possible issues with creep and shrinkage. However, TxDOT has used RCA in some structural applications and is monitoring them.
- RCA that originated as concrete with rounded aggregate yields a new product with particles having fractured angular shapes for increased paste bond.
- RCA eliminates the development of waste piles of concrete.
- Haul distances are decreased with RCA because the waste stream of RCA usually originates and is consumed within the same urban area. This decreases energy consumption and helps improve air quality through reduced mobile source emissions.
- Over 10 years experience TxDOT believes RCA provides a cost benefit in specific applications. The RCA is bid as an option, so the economics of the low bid system drives the use of RCA.

TxDOT has also established mechanisms, such as waste stream documentation, to identify the source of the materials.
Michigan DOT (MDOT)
Michigan DOT shared the following experiences and practices with FHWA’s research team: (lxxii)

- RCA used in the base and sub-base material can have performance comparable to virgin aggregate where recycled material is allowed.
- Damage to the highway infrastructure can be reduced due to proximity of aggregate crushing plants.
- Cracking performance problems in RCA pavements can be reduced when the old pavement is crushed to a smaller aggregate size.
- Using RCA in the Detroit metropolitan region is more advantageous than in rural areas of the state, since sources of old concrete are readily available and virgin aggregate sources are not as plentiful. The proximity to metro areas of the RCA production plants also makes this aggregate economically attractive for commercial uses in base and parking lots.
- A recent value-engineering proposal for RCA in the pavement structure on US-41 resulted in savings of $114,000 on a 3 million dollar project. This savings was shared in equal parts by the contractor and the state.
- Normally commercial sources of concrete are not allowed for recycling in the crushing plants. Most recycled material comes from the MDOT’s reconstruction projects. This assures a consistent source of original aggregate. MDOT has also used certification of recycling aggregate producers and the approval of stockpiles.
- Changes in the design on the permeable base allow RCA to be used when the density of material is increased and the design of the drainage system is modified.

Minnesota DOT (Mn/DOT)
Minnesota DOT’s (Mn/DOT) experience with the use of RCA are as follows: (lxxiii)

- Statewide use of RCA is permitted in the Mn/DOT Standard Specifications for Construction. The specifications establish that RCA can be used as coarse aggregate in Portland cement concrete (PCC) in section 3137.2 B, as aggregate for surface and base courses in section 3138.2 A, and as granular material in section 3149.2.
- Minnesota currently uses almost 100 percent of the concrete removed from its pavements as dense graded aggregate base. This material must meet the 3138.2 section of Mn/DOT specification and can include a maximum of 3 percent by mass of asphalt binder from recycled asphalt pavement.
- From the late 1970s through the 1990s, RCA was used as coarse aggregate for PCC pavements on over 20 projects. Today, Mn/DOT uses a 60-year pavement design life on its high-volume freeways and a 35-year design life on all others. The associated requirements have limited the economic use of RCA in concrete pavements. Currently, Mn/DOT is incorporating RCA primarily as aggregate base in highways projects.
Observations suggest that RCA used in the base and sub-base material performs similarly to new aggregate where recycled material is allowed. Research is underway to establish laboratory performance parameters for RCA used in aggregate base and sub-base.

Rubblization, crack & seat, and unbonded concrete overlay have been used as reconstruction strategies. All of these processes have shown to be provide good performance. Unbonded concrete overlay is the most used technique of pavement rehabilitation in the state.

It is a common practice in Minnesota to crush the material on site. This lowers the transportation costs and has less effect on traffic.

Preservation of natural aggregate resources is a priority for Mn/DOT as a 10-year aggregate availability study identified these materials as potentially in short supply.

RCA is being included in a permanent rule relating to Beneficial Use of Solid Waste, where RCA will be considered a standing beneficial use and not subject to review or permitting by Pollution Control Agency.

Beneficial Use of Solid Waste rule will be instrumental in establishing a database of information on other non-RCA recycled source materials, conditional uses, evaluation process, and stockpiling requirements.

Lack of data and base line information on effluent leachate and particulate quality was considered a potential barrier in light of new NPDES and TMDL rule or other local regulations.

Experiences shared by industry in Minnesota included:
- There is no need to remove fines when RCA is used in absence of drainage layers and/or perforated drainage pipes, making the use of RCA more efficient.
- Recycled material coming typically from Mn/DOT’s reconstruction projects may assure a consistent source of aggregate.
- Steel removal has become easier through years, generating a cleaner recycled aggregate.

Recommendations provided by Mn/DOT for using RCA in state highways include the following: (lxxiv)
- Washing of RCA is required if used in PCC pavements in order to eliminate excess fines.
- Quality requirements for new aggregate do not specifically apply to RCA when the pavement comes from a known source.
- In presence of drainage layers and/or perforated drainage pipes:
  - A blend of RCA with new aggregate may be used as subgrade when at least 95 percent of the RCA is retained on the 4.75 mm sieve.
  - RCA may be used up to 100 percent in construction of the filter/separation layer under a permeable aggregate base drainage layer in accordance with the applicable drainage specifications.
• Mn/DOT Research Record of March 1995, “Uses of Crushed Concrete Products in Minnesota Pavement Foundations,” provides methods for mitigating precipitate and drainage problems.

**Caltrans**
Caltrans initially limited the amount of RCA to 50 percent by weight of the total aggregate. Today, a 100 percent of recycled concrete aggregate is allowed by a special provision. Caltrans is working with the concrete and aggregate industries to develop further applications/uses of RCA. Recently, the City of San Francisco approved the use of RCA as aggregate concrete in curbs, gutter, sidewalk, and street base. Ready Mix Industry suggested that plastic Portland cement concrete (PPCC) can be reclaimed and separated in coarse aggregate, fines, and slurry. The reclaimed aggregate is used as aggregate for concrete or base material. Furthermore, the reclaimed slurry may also potentially be reused Ready Mix Industry suggested that the concrete plant could become a zero-waste facility through the reclaim of PPCC and hardened concrete. As a result of a joint committee among City of Los Angeles, Concrete and recycled aggregate producers (“Greenbook”), reclaimed PPCC is allowed to be used in concrete mixtures in a maximum of 15 percent by volume of concrete; RCA is allowed to be used in concrete in a maximum of 30 percent by weight of total aggregate. The City of San Francisco recently approved the use of RCA non-structural concrete. Orange County and Industry are working together to develop specifications for successful use of RCA.

**Virginia DOT (VDOT)**
Virginia DOT has found that even though the initial production cost of RCA may be higher than that of new aggregate, the location of RCA plants near project areas lowers the final cost of using RCA primarily due to reduced hauling and overhead costs. VDOT uses RCA in base, sub-base, synthetic reefs, and embankments. One example of VDOT’s use of RCA in sub-base aggregate is the I-66 project, which won the National Concrete Paving Award after completion. This project was a part of a $140 million reconstruction program on a section of Interstate 66 in Fairfax and Prince William Counties.

**Illinois DOT (IDOT)**
Illinois DOT is among agencies allowing the use of RCM as a coarse aggregate in aggregate surface courses, granular embankments, stabilized bases, and subbase courses provided the project materials’ specifications are not compromised. Illinois DOT used 321,000 tons in 2001, reducing landfill space needs.

**Indiana DOT (INDOT)**
At the Indiana Department of Transportation, most concrete structures that meet the requirements of INDOT Specifications and are proportioned according to American Concrete Institute Specification 211.1 may utilize as much as 77 percent recycled materials by weight, and concrete bridge decks may consist of as much as 50 percent recycled materials by weight.

**Use of Recycled Concrete as Aggregate in PCC Pavements**
AASHTO has a [Specification for Recycled Concrete as Aggregate in PCC Pavements](#). The specification covers coarse aggregate derived from reclaimed...
concrete for use in Portland cement concrete. The specification is not intended for use when lightweight, high density, or other specialty Portland cement concrete applications are required. When aggregate materials are properly processed and manufactured to the requirements of this specification, combined and mixed in accordance with the appropriate requirements, and placed, consolidated, and cured properly, a Portland cement concrete structure of acceptable strength and durability can be produced. The following practices are recommended: (lxxix)

- The engineer should ensure that reclaimed concrete source materials are not contaminated with extraneous solid waste or hazardous materials. Methods and criteria for examining and approving reclaimed concrete materials prior to use should be established by the specifying jurisdiction. The presence of deleterious materials in aggregates used in the production of Portland cement concrete could adversely affect concrete setting time and/or strength, and could also induce expansive reactions that could result in premature deterioration of the concrete structure. Strict quality control and quality assurance procedures (outlined in AASHTO Standard Practice R 18-97) should be implemented to ensure that reclaimed concrete aggregate material used as coarse aggregate in the production of Portland cement concrete will not adversely affect the quality of the concrete product.

- Reclaimed concrete aggregate should not contain: clay lumps and friable particles, chert, and coal and lignite or other deleterious substances that exceed the maximum allowable amounts listed in the AASHTO specification.

- Reclaimed concrete aggregate should not contain more than 1.0 percent by mass of material finer than the 75-Fm (No. 200) sieve. This maximum quantity may be increased to 1.5 percent by mass if the fines are derived from the aggregate crushing process.

- Reclaimed concrete aggregate when sampled and tested according to AASHTO Standard T260 should not contain chloride ion in excess of 0.6 lbs of chloride ion per cubic yard of Portland cement concrete.

- The engineer should be aware that coarse reclaimed concrete aggregate may contain air entrained concrete mortar and, therefore, may be highly absorptive and can exhibit low and highly variable specific gravity values. Utilizing highly absorptive aggregates (coarse and fine) that do not exhibit consistent specific gravity values in Portland cement concrete can adversely affect the weighing and batching process in the concrete production operation.

- Some reclaimed concrete aggregate materials may yield higher than expected soundness loss values when subjected to conventional sulfate soundness testing methods. Such testing methods may not be reliable for reclaimed concrete aggregate soundness testing.

- Coarse reclaimed concrete aggregate should either conform to the coarse aggregate gradation requirements prescribed in AASHTO M 43 for the size number specified in the contract documents, or should conform to the coarse aggregate gradation requirements of the specifying jurisdiction. Where coarse aggregate size numbers like 357 or 467 of AASHTO M 43 or other size numbers
that exhibit a range of particle size distributions that can result in aggregate segregation are used, the aggregate should be furnished in at least two separate sizes. If the contractor/supplier wishes to use combinations of reclaimed concrete aggregate or reclaimed concrete aggregate and other approved aggregate materials, a request should be made to the engineer for approval. The percentage of combined materials should be established as part of a presubmitted blended aggregate combination. At the engineer’s discretion, revised Portland cement concrete mix designs should be required when percentages of materials change.

- If reclaimed concrete aggregate is blended with other approved aggregates, this should be accomplished by mechanical interlock blending or belt blending to ensure uniform proportioning. Other methods of blending should be permissible if it can be demonstrated to the engineer that the alternate blending method will prevent segregation.

- Reclaimed concrete aggregate should comply with the Los Angeles abrasion or Micro Deval test requirements for the various class designations shown in the AASHTO specification.

- Reclaimed concrete aggregate soundness testing should be required at the discretion of the engineer. Alternative soundness test methods and acceptance criteria are included in the AASHTO specification.

- Reclaimed concrete aggregate for use in concrete that will be subject to in-service wetting, extended exposure to humid atmosphere, or contact with moist ground should not contain any materials that are reactive with alkali components in the cement in an amount sufficient to cause excessive expansion of mortar or concrete, except that if such materials are present in injurious amounts, the coarse aggregate may be used with a Portland cement containing less than 0.6 percent alkalies calculated as sodium oxide equivalent or with the addition of a material that has been shown to prevent harmful expansion due to the alkali-aggregate reaction. Alkali reactivity should be testing in accordance with AASHTO T 303 when alkali silica reaction is suspected, in accordance with ASTM C 586 when alkali carbonate reaction is suspected, or in accordance with other equivalent test methods approved by the specifying jurisdiction. A listing of alternative test methods are in AASHTO’s specification.

- Reclaimed concrete aggregate for use in concrete that will be subjected to freeze-thaw action should not contain aggregate components that expand and result in D-cracking of the concrete. When potential D-cracking is suspected by the specifying jurisdiction, the reclaimed concrete aggregate should be tested in accordance with ASTM C 666 or other equivalent method and should meet the acceptance requirements of that jurisdiction.

- Reclaimed concrete aggregate should meet the flat and elongated particle requirements of the specifying jurisdiction.

- Reclaimed concrete aggregate should be saturated with water for a time period that is sufficient to saturate all particles, prior to introducing the reclaimed concrete aggregate into a Portland cement mix, by means of a water sprinkling system or another approved method. At the time of batching, the reclaimed
Concrete aggregate should contain water in excess of the saturated surface dry condition. Provision should also be made for the free drainage of excess water.

**Reclaimed Concrete Aggregate for Unbound Soil-Aggregate Base Course**

AASHTO developed a Specification for Reclaimed Concrete Aggregate for Unbound Soil-Aggregate Base Course: AASHTO Designation: M 319-02. When properly processed, hauled, spread, and compacted on a prepared grade to appropriate density standards, reclaimed concrete aggregate used alone or blended with natural or crushed aggregate can be expected to provide adequate stability and load support for use as road or highway base courses, the uppermost unbound granular layer of the pavement structure. The following practices are recommended:

- The purchaser or specifier should reference the AASHTO specification, grading to be furnished for the granular base, soundness testing requirements, and any additions to or exceptions from the AASHTO specification. The percentage of materials should be established as part of a pre-submitted blended aggregate combination.

- Reclaimed concrete aggregate should consist of crushed concrete material and natural aggregate particles derived from the crushing of Portland cement concrete that are hard, durable fragments of stone, gravel, slag, crushed concrete, or sand.

- Reclaimed concrete aggregate should contain not more than five percent bituminous concrete materials by mass. Reclaimed concrete aggregate should contain not more than five percent brick by mass.

- Reclaimed concrete aggregate material should be free of all materials that fall under the category of solid waste or hazardous materials as defined by the state or local jurisdiction.

- Reclaimed concrete aggregate should be substantially free of wood, metal, plaster, and gypsum board, when these materials are not classified as solid waste. Substantially free, in the context of this specification, should mean percentages of undesirable materials that are less than the following: wood—0.1 percent maximum; metals—0.1 percent maximum; plaster and gypsum board—0.1 percent maximum. At the engineer’s discretion these respective quantities may be adjusted if, in the engineer’s opinion, such adjustment will not impact the performance of the base course.

- The engineer should provide appropriate construction specifications to ensure compaction to an extent that further densification of the compacted pavement from traffic loadings will be insignificant. At the time of placement, the reclaimed concrete aggregate material should contain moisture approximately equal to the optimum moisture content necessary to make certain that the design density requirements are obtained when the material is compacted. Reclaimed concrete aggregate can be expected to exhibit higher absorption than natural aggregate materials. Accordingly, the engineer should expect to experience moderately higher optimum moisture content values than would be expected with natural aggregate materials. The reclaimed concrete aggregate should be compacted using...
vibratory or other proven effective rollers or tampers to achieve the required density results.

- When the engineer permits the contractor/supplier to combine reclaimed concrete aggregate with other approved aggregates, this should be accomplished by mechanical interlock blending or belt blending to ensure uniform mixing. The contractor/supplier may use other methods of blending if it can be demonstrated to the engineer that the alternate blending method will prevent segregation.

- The engineer should be aware of the highly alkaline nature of reclaimed concrete aggregate, the relatively high degree of solubility of these alkaline materials, and the potential increase in pH that could occur in waters percolating through a reclaimed concrete aggregate base. Depending on the sensitivity of local soils, surface waters, and groundwater to the presence of alkaline material, the engineer should set appropriate limits on the proximity of placement of reclaimed concrete aggregate relative to groundwater and surface waters. Additionally, the presence of water percolating through reclaimed concrete aggregate will induce a corrosive solution with a pH of approximately 11 to 12. Therefore, reclaimed concrete aggregate should not be used in the vicinity of metal culverts such as aluminum culverts that are sensitive to highly alkaline environments.

- The engineer is cautioned to prevent, or minimize when possible, the use of reclaimed concrete aggregate over a geotextile drainage layer, gravel drain fields, drain field piping, or open soil-lined stormwater retention or detention facilities. Soluble minerals rich in calcium salts and calcium hydroxide can be hydraulically transported from the reclaimed concrete aggregate material. When this occurs and the reclaimed concrete aggregate is located above such porous drainage systems, there is a tendency for the referenced minerals to precipitate out of solution and bind the drainage structure. The mineral deposits formed are sometimes referred to as tufa-like or Portlandite deposits. Over time the permeability of the drainage system can be reduced.

- The engineer should be aware that reclaimed concrete aggregate used as base course could, with time, gain strength and exhibit a corresponding loss of permeability in the base course layer. This is due to residual cementitious reactions in the concrete material. If the base course is intended for use as a drainage layer, then the fine portion of the reclaimed concrete aggregate should be removed or modified to reduce the potential for this occurrence.

- The engineer is cautioned that some reclaimed concrete aggregate materials will yield high soundness loss values when subjected to conventional sulfate soundness testing methods, and such testing methods may not be suitable for reclaimed concrete aggregate soundness testing.

- The engineer is cautioned to ensure that reclaimed concrete source materials are not contaminated with extraneous solid waste or hazardous materials. Methods and criteria for examining and approving reclaimed concrete materials prior to use should be established by the specifying jurisdiction.

- Reclaimed concrete aggregate should be limited in plastic soils such that the minus 0.425-mm (No. 40) sieve material when tested for liquid limit (T 89)
should not be greater than 30 and the plasticity index (T 90) should not be greater than four, and/or at the discretion of the engineer, the sand equivalent value (T 176) of the minus 0.425-mm (No. 40) sieve material should be a minimum of 25 percent.

- Reclaimed concrete aggregate should have a percentage of wear by the Los Angeles abrasion test (T 96) of not more than 50 percent.
- Reclaimed concrete aggregate should have a percentage of wear by the Los Angeles abrasion test (T 96) of not more than 50 percent.
- Reclaimed concrete aggregate soundness testing should be required at the discretion of the engineer.

**Recycled Roofing Shingles**

Waste roofing shingles are generated during the demolition of existing roofs, and from scraps of trimmed asphalt shingles. Consumer aged waste shingles are referred to as tear-off shingles (90-95 percent of the available material), whereas manufacturer waste is known as roofing shingle tabs or punch-outs, which includes “out-of-spec” and mis-colored or damaged shingles. Both materials are shredded in two to three stages to achieve the desired size.

Roofing shingle tabs are used as an asphalt cement modifier often resulting in a stiffer mix with improved temperature susceptibility and rut resistance. Tear-off shingles may be used in the same way, but are difficult to process due to the presence of foreign materials, and may also be in an irreversible age-hardened state. In general, both types may function as fine aggregate or mineral filler depending on the size of the shredded material. Roofing shingles may be susceptible to moisture-related damage thus mix designs should include an anti-strip or retained stability test.\(^{(lxxxii)}\)\(^{(lxxxiii)}\)

FHWA’s recommends asphalt shingles for use as asphalt cement modifier when contaminants and debris can be removed, and as a binder, aggregate substitute, or mineral filler, guidance which is available at their recycled waste materials website. AASHTO and RMRC have developed a Draft White Paper for Recycled Asphalt Shingle as an Additive in Hot Mix Asphalt,\(^{(lxxxiv)}\) which reviews state specifications and other sources regarding addition rates of recycled asphalt shingles, found addition rates of 3 to 10 percent. The spec is likely to recommend an approach limiting the addition rate to direct performance criteria that include gradation requirements of the new hot mix asphalt, the performance grade of the virgin asphalt binder, and the volumetric properties of the new hot mix asphalt. The white paper authors believe that the principles in AASHTO MP-2, “Superpave Volumetric Mix Design” Appendix X1, which establishes various approaches to the use of RAP in Superpave mixtures depending on the percentage of RAP intended for use, are applicable, with modification, to the use of recycled asphalt shingles in hot mix asphalt applications.

**State DOT Experiences with Use of Recycled Roofing Shingles**

PennDOT, Mn/DOT, Illinois DOT and Iowa DOT are among the many states that have investigated waste roofing shingles in combination with bituminous concrete mixes. Pennsylvania has determined that a bituminous concrete modified with properly shredded fiberglass shingle tabs performs as well as a conventional bituminous pavement.
Minnesota has had similar results with both felt and fiberglass shingle tabs. Both states were able to reduce the amount of virgin asphalt cement required, a potential for cost savings. Both states have issued provisional specifications allowing limited amounts of processed shingle tabs in bituminous concrete mixes. Iowa DOT inspected efforts in utilizing bitumen tear-off shingles. One year after construction, the roadway remained workable and virtually dust free. NCDOT added usage of post-industrial scrap shingles to its 2002 Standard Specification Books as an alternate for all construction contracts.

Mn/DOT has conducted several projects on the use of roofing shingles in HMA pavements. Findings from a study on their use in dense-graded mixes indicated that the addition of roofing shingle waste can result in a reduction in optimum neat binder content, enhance the ability to densify under compaction, and increase the plastic strain component in permanent deformation measurements. Cold tensile strengths were also reduced, but the impact on the corresponding strains was dependent on the type of shingle waste and the grade of asphalt cement. This finding could indicate that HMA’s potential for thermal cracking could be reduced by adding roofing shingle wastes.

Mn/DOT also studied the use of roofing shingle waste in stone matrix asphalt mixes. The research showed that adding 10 percent of manufactured roofing shingle waste to the mix resulted in a 25- to 40-percent reduction in the required neat binder content. Mn/DOT completed a project in 1991 that used from 5 to 7 percent asphalt shingles by weight of mix. The shingles were ground to a uniform consistency resembling coffee grounds and were added to a drum mix plant as if they were recycled asphalt pavement. No construction problems were noted; further, no problems have been reported regarding pavement performance.

NJDOT experimented with an asphalt cold-patch material made from old roofing material. The resulting patch material showed only minor signs of distress after 22 months of service. In comparison, conventional cold-patch material generally lasts only three to six months.

Illinois DOT has expressed concerns regarding the presence of any asbestos in tear offs, glass felt tabs, and/or from storage cross-contamination, along with the presence of any foreign debris from nails, wood, and insulation, and the environmental impact of polynuclear aromatic hydrocarbons present in roofing tars on plant and paving site air emissions.

**Fly Ash**

Fly ash is the finely divided residue that results from the combustion of pulverized coal. This airborne residue exits a coal combustion chamber with the flue gas and is removed from the flue gas by electrostatic precipitation, baghouses, or other particulate control devices prior to the introduction of scrubber reagents. Use of recycled fly ash reduces the solid-waste disposal problems associated with fly ash, reduces the cost of concrete production, and improves the physical and mechanical properties of concrete. Almost a quarter of the fly ash produced is recycled, most of it in Portland cement concrete, where it has been successfully used for 60 years. Currently, over 20 million metric tons (22 million tons) of fly ash are used annually in a variety of engineering applications. Typical highway engineering applications include: Portland
fly ash may be categorized as two types. One is self-hardening and the other is non-self-hardening. Both types contain siliceous or siliceous and aluminous materials, which in the presence of lime or Portland cement and water react to form a cementitious material. The self-hardening type will form cementitious material in the presence of water alone.

AASHTO M 295 delineates the physical, chemical, and mechanical properties requirements for fly ash to comply with the Class F or Class C specifications. Generally speaking, Class F fly ash is pozzolanic, with little or no cementing value alone, and Class C has both self-cementing properties as well as pozzolanic properties.

The following uses and benefits are taken from FHWA’s Fly Ash Fact Sheet for Engineers.

**Fly Ash in PCC**

Fly ash is most commonly used as a pozzolan in PCC applications. Pozzolans are siliceous or siliceous and aluminous materials, which in a finely divided form and in the presence of water react with calcium hydroxide at ordinary temperatures to produce cementitious compounds. The unique spherical shape and particle size distribution of fly ash make it a good mineral filler in hot mix asphalt (HMA) applications and improves the fluidity of flowable fill and grout. The consistency and abundance of fly ash in many areas presents unique opportunities for use in structural fills and other highway applications. Fly ash utilization, especially in concrete, has significant environmental benefits including: 1) increasing the life of concrete roads and structures by improving concrete durability, 2) net reduction in energy use and greenhouse gas and other adverse air emissions when fly ash is used to replace or displace manufactured cement, 3) reduction in amount of coal combustion products that must be disposed in landfills, and 4) conservation of other natural resources and materials.

Benefits to concrete vary depending on the type of fly ash, proportion used, other mix ingredients, mixing procedure, field conditions and placement. Some of the benefits of fly ash in concrete higher ultimate strength, improved workability, reduced bleeding, reduced heat of hydration, reduced permeability, increased resistance to sulfate attack, increased resistance to alkali-silica reactivity (ASR), lowered costs, reduced shrinkage, and increased durability. Proper design and construction practices should address the potential for decreased air entraining ability with high carbon fly ash, and potential for reduced durability, reduced early strength, and reduced heat of hydration in colder climates, as indicated in FHWA’s Chapter 3 (Fly Ash in Portland cement concrete) on the topic. Mass Highway also has a spec for fly ash use to mitigate Alkali-Silica Reactivity (ASR) in Portland cement concrete that says fly ash should constitute 15-30 percent of the cementitious material (15 percent by weight of the design cement content, any additional fly ash will be considered as fine aggregate); see Spec M4.02.00.

**Fly Ash in Stabilized Base Course or Pozzolanic-Stabilized Mixtures (PSMs)**

Fly ash and lime can be combined with aggregate to produce a quality stabilized base course. These road bases are referred to as pozzolanic-stabilized mixtures (PSMs). Typical fly ash contents may vary from 12 to 14 percent with corresponding lime contents of three to five percent. Portland cement may also be used in lieu of lime to
increase early age strengths. The resulting material is produced, placed, and looks like cement-stabilized aggregate base, but has the following advantages over other base materials: use of locally available materials, strength and durability, lower costs, autogenous healing, increased energy efficiency. This mixture also can be placed with conventional equipment. PSM bases require attention to seasonal limitations and traffic loading before complete curing.

Proper sealing and protection with asphalt or other surface treatment are required to improve skid resistance. FHWA’s Chapter 4 (Fly Ash in Stabilized Base Course) provides more information on use of fly ash in stabilized base courses. Research has demonstrated a correlation between compressive strength gain and increase in resilient modulus as a function of curing time with the addition of fly ash to stabilized recycled concrete base. Also, a study on mechanical stabilization of cemented soil-fly ash mixtures with recycled plastic strips found ranges in strength values suitable for a high-quality stabilized base course for a highway pavement; the use of fiber reinforcement significantly increased the postpeak load carrying capacity of the mix and thus the fracture energy, leading the researchers to conclude that the lean cementitious mix containing recycled materials offer a lot of promise as an alternative material for civil engineering construction.

Fly Ash as a Flexible Base
Several TxDOT districts have been experimenting with the use of fly ash treated (or cured) with water (hydrated fly ash) as a flexible base. They found that hydrated fly ash very easily meets strength criteria for flexible base materials and that the material can satisfactorily function as a road base for an extended period. While the Texas Transportation Institute (TTI) noted that hydrated fly ash appears to have great potential for use as a flexible base material, appropriate methods must be adopted in its production or else durability problems may arise. The researchers made the following observations and recommendations for practice on the use of fly ash as a flexible base:

- Strict adherence to the gradation specification may not be needed; it was observed in the field that the material undergoes further hydration after placement, thus forming a stiff, nearly homogeneous layer.
- Laboratory compaction tests using hydrated fly ash with two different gradations (gap-graded and well-graded) revealed that both gradations gave nearly the same maximum dry density values, though at different moisture contents. Powdered fly ash hydrated at lower moisture contents provides much higher strengths, resulting in better resistance of the aggregate to degradation. Also, thorough mixing with the water should be emphasized. Aggregates produced using higher hydrating moisture contents possess lower unit weight and lower strength.
- Care must be taken during the curing process to ensure that the material attains to the required level of strength before it is milled. Otherwise, the material may not meet specifications for degradation and durability.
- Care must be taken during the curing process and during construction to ensure that the material is not allowed to dry excessively. If allowed to dry, it will form compounds that may impair the durability of the material.
• Sufficient allowance should be made for subsequent wetting during curing and construction, as hydrated fly ash has a high water demand. Shrinkage cracks may appear if the fly ash has not reached an advanced stage of hydration in the curing ponds.

**Fly Ash in Flowable Fill**
Flowable fill is a mixture of coal fly ash, water, and Portland cement that flows like a liquid, sets up like a solid, is self-leveling, and requires no compaction or vibration to achieve maximum density. In addition to these benefits, a properly designed flowable fill may be excavated later. For some mixes, an optional filler material such as sand, bottom ash, or quarry fines is added. Flowable fill is also referred to as controlled low-strength material, flowable mortar, or controlled density fill. It is designed to function in place of conventional backfill materials such as soil, sand, or gravel and to alleviate problems and restrictions generally associated with the placement of these materials. Using flowable fill allows placement in any weather, even under freezing conditions; achieves 100 percent density with no compactive effort; fills around/under structures inaccessible to conventional fill placement techniques; increases soil-bearing capacities; prevents post-fill settlement problems; increases the speed and ease of backfilling operations; decreases the variability in the density of the backfilled materials; improves safety at the job site and reduces labor costs; decreases excavation costs, and allows easy excavation later when properly designed. FHWA provides guidance for fly ash use in flowable applications in Chapter 5 (Fly Ash in Flowable Fill). Mass Highway has a spec for use of fly ash as an ingredient in very flowable Controlled Density Fill, available as Spec M4.08.00.(xcviii)

**Fly Ash in Soil Improvement**
Fly ash is an effective agent for chemical and/or mechanical stabilization of soils. Typical applications include: soil stabilization, soil drying, and control of shrink-swell. Fly ash eliminates need for expensive borrow materials, expedites construction by improving excessively wet or unstable subgrade, promotes cost savings through reduction in the required pavement thickness by improving subgrade conditions, and can reduce or eliminate the need for more expensive natural aggregates in the pavement cross-section. Use of fly ash as an admixture in the stabilization of a soft marine clay has resulted in stabilized samples with an improved strength more than 75 times that of the untreated clay. Incorporation of fly ash also improved drainage property by at least one order of magnitude and reduced both the plasticity and compression indices by about 69 and 23 percent, respectively. Leachate investigation carried out on fly ash-stabilized soils indicated that chromium was well-below the World Health Organization drinking water limit, while nickel and lead were in excess of the limits. Nickel and lead leachate concentrations diminished to below the acceptable drinking water limits over about 130 and 110 days, respectively.(xcix)

Important considerations for soil improvement projects using fly ash are:

- The rate of the hydration reaction upon exposure to water.
- Soil moisture content at the time of compaction.
• Fly ash with a sulfate content greater than 10 percent may cause soils to expand more than desired.
• In many cases, leaching tests may be required by local and state agencies.

FHWA’s guidelines for use of fly ash in soil improvements are discussed in their Chapter 7 (Fly Ash in Soil Improvement).

**Fly Ash in Asphalt Pavements and in Pavement Subsealing**
Fly ash can be used as mineral filler in HMA paving applications. Mineral fillers increase the stiffness of the asphalt mortar matrix, improving the rutting resistance of pavements, and the durability of the mix. Fly ash will typically meet mineral filler specifications for gradation, organic impurities, and plasticity. Benefits include reduced potential for asphalt stripping due to hydrophobic properties of fly ash. Lime in some fly ashes may also reduce stripping and may afford a lower cost than other mineral fillers. FHWA’s guidelines for use of fly ash are in Chapter 8 (Fly Ash in Asphalt Pavement).

Grouts are proportioned mixtures of fly ash, water, and other materials used to fill voids under a pavement system without raising the slabs (subsealing), or to raise and support concrete pavements at specified grade tolerances by drilling and injecting the grout under specified areas of the pavement. Fly ash grouts can be used to correct undermining without removing overlying pavement and can be accomplished quickly with minimum disturbance to traffic. Fly ash grouts also develop high ultimate strength; however, they require curing period before extremely heavy loading because of low early strength and require confinement of the grout mixture under pavement.

**Fly Ash in Structural Fills/Embankments**
Fly ash can be used as a borrow material to construct fills and embankments. When fly ash is compacted in lifts, a structural fill is constructed that is capable of supporting highway buildings or other structures. Fly ash has been used in the construction of structural fills/embankments that range from small fills for road shoulders to large fills for interstate highway embankments. When used in structural fills and embankments, fly ash offers several advantages over soil and rock. It is cost-effective where available in bulk quantities and eliminates the need to purchase, permit, and operate a borrow pit. Fly ash can be placed over low bearing strength soils and ease of handling and compaction reduces construction time and equipment costs. Further practice recommendations are detailed in FHWA’s Chapter 6 (Fly Ash in Structural Fills/Embankments) and AASHTO’s specification.

AASHTO’s draft specification for use of fly ash in embankments and structural fills identifies a number of recommended practices:

- Fly ash must be conditioned at the source prior to use. If self-hardening fly ash is used, this conditioning will result in rapid curing and hardening, making the cured product unsuitable for use without reprocessing (by recrushing) of the material prior to placement.
- The purchaser or specifier should include in the purchase order or contract documents references to the spec and to state and/or local environmental protection agency requirements, as well as grading and blending requirements, type or types of fly ash specified, and exceptions or additions to the spec.
• Due to the fact that local agencies have widely differing policies and/or regulations regarding where and how fly ash can be used as a structural fill or embankment material, out of concerns relative to leachate that might contain elevated levels of contaminants, local requirements must be investigated when considering the use of fly ash as a structural fill or embankment material.

• The engineer should be aware that the engineering properties of fly ash are similar to those of non-cohesive silt materials. The silt-like nature of fly ash is sufficiently different from traditional embankment materials that specialized practices are required for the successful construction of fly ash embankments.

• Proper compaction is critical to the performance of a conventional soil embankment or structural fill and may even be more so when recycled materials, such as fly ash, are used in such construction. Fly ash can be expected to exhibit high water absorption and, because of the fineness (size) of the material, a propensity to retain inter-granular water. As a result, fly ash, in most instances, will exhibit a higher optimum moisture content and a lower maximum dry density value than conventional embankment materials. Maximum dry density values may also vary somewhat from day to day or even from truck load to truck load. The engineer is cautioned to provide appropriate construction specifications to ensure compaction of the embankment to the extent that further densification of the compacted embankment from traffic loadings will be insignificant. At the time of placement, the fly ash material should contain the necessary moisture content to ensure that the design density requirements are obtained when the material is compacted.

• If necessary for proper compaction, water should be added to the fly ash by the use of a water distribution tank trucks. The water and fly ash should be mixed using a rototilling mixer or other approved method. At the time of compaction, the fly ash should have a moisture content that will result in an after compaction dry density greater than that specified.

• The first pass in the compaction process should be accomplished by the method known as tracking. This involves the use of a bulldozer track to accomplish initial compaction. The bulldozer is moved progressively across the fly ash structural fill or embankment until the entire area is tracked.

• The fly ash structural fill or embankment should subsequently be compacted using pneumatic tired, vibratory or other approved types of compaction equipment. The equipment should work from the edge of the structural fill or embankment toward the center.

• At the completion of each days work, the surface of the fly ash structural fill or embankment should be sealed. This means that it should be graded after compaction so that rain would tend to flow off the embankment rather than penetrate into the material.

• Fly ash should be compacted using vibratory, pneumatic tired or other proven effective rollers or tampers, until the density no longer increases. Compaction techniques may vary among jurisdictions. However, as a matter of practicality lift thicknesses for fly ash of 20 or 25 centimeters (8 or 10 inches) are generally
specified. A defined and effective rolling pattern should be developed. Acceptance of each lift should be based on in-place density as a percentage of maximum dry density as determined by AASHTO T 310.

- Delivery of fly ash should be in closed or covered trucks. To avoid the dispersal of fly ash, deliveries of fly ash should not be placed in temporary stockpiles on the project site and should be discharged directly to the embankment site where placement and compaction will take place. The delivery, placement, spreading, and compaction of fly ash should be carefully planned so that the work can proceed from one step to the next without delay.

- Before construction of the fly ash embankments begins, containment berms should be constructed to a thickness of at least six feet at the top of each containment berm segment and located on the outside limits of the embankment footprint. The containment berm segments should have a trapezoidal cross section and side slopes of 2:1 or less. As the structural fill or embankment is constructed upward, containment berms should be placed on the outside of each new tier before placing fly ash. For narrow embankments, like ramps, the engineer may consider narrower containment berms.

- The natural soil materials should be placed in 20 centimeter (8-inch) loose lifts. Containment berms should be compacted as required by the specifying agency. Fly ash material should also be spread into loose lifts of approximately 20 centimeter (8-inch) thickness. The engineer may consider thicker lift dimensions if it can be satisfactorily demonstrated with a test section that adequate compaction can be achieved over the full depth of the thicker lift.

- Fly ash should be conditioned for dust control and to prevent erosion by the addition of from 10 to 15 percent water by mass at the source site prior to delivery. This conditioning may include subsequent storage (stockpiling) of the fly ash after it has had water mixed with it for a period of 24 hours or more until the water is evenly dispersed. If the supplier can demonstrate that water is evenly distributed throughout the fly ash, then stockpiling may not be required.

- As fly ash that is not protected from the elements may become saturated with rainwater and erode or release soluble components, there should be no large-scale storage of fly ash at the project construction site. Small amounts of fly ash may be stored for short periods of time to facilitate construction specifications when done in accordance with the project sediment and erosion control plan.

- The contractor should make available and use water, if necessary, to control the generation of dust due to drying of the fly ash.

- The final grade of the fly ash structural fill or embankment should be accomplished by the placement of at least 60 centimeters (24 inches) of compacted natural soil material at the top of the embankment, placed in four 20-centimeter (8-inch) loose lifts. The entire structural fill or embankment structure, with the exception of the roadway pavement structure, should be covered with at least 20 centimeters (8 inches) of topsoil.
• In the event impermeable containment below the fly ash structural fill or embankment is required by the specifying agency, then such containment should be accomplished in accordance with the permeability requirements of the specifying jurisdiction.

• If chemically stabilized fly ash is specified, the contractor should submit a mix design for approval by the engineer. The materials should be mixed in a pugmill or other approved method. The use of certain stabilizing agents may elevate pH values of aqueous solutions that may contact metal structures or conduits within the stabilized fly ash embankment. (33)

In FHWA’s Fly Ash Fact Sheet for Engineers, FHWA points out potential frost susceptibility problems with fly ash and recommends that a layer of coarse-grained material be placed below the embankment to break the capillary structure and prevent the vertical migration of water to freeze zones. (cii) Most states are concerned with the potential for capillary water migration and the resulting loss of stability, and frost susceptibility in fly ash structural fills and embankments. As a result, many states require the placement of special materials to prevent ground water migration. In some cases a highly granular layer of soil material at the bottom of the fly ash embankment is specified. This acts as an openly porous structure, providing a discontinuity to the vertical capillary movement of water. In other cases a cover of two or three feet of traditional soil material over the top of the fly ash that prevents the penetration of frost into the fly ash layer from above (thus preventing a site within that layer where ice lens and ultimately frost heating may occur) is specified. (ciii)

• The vertical migration of water may be minimized or prevented by the placement of an open-pored granular material at the base of the fly ash structural fill or embankment. This underlayer effectively stops vertical water migration because the soil pore structure is so large the surface tension of water is not sufficient to move the water upward. This granular layer at the base of the embankment will prevent the possibility of saturation and loss of shear strength.

• The onset of freezing in the upper portion of the embankment may be prevented from occurring within the fly ash layer by the placement of sufficient cover material. Generally, frost will penetrate into the soil as a function of the prevailing winter temperatures for a given geographic area. In order to prevent the penetration of frost in most areas, at least 90 centimeters (36 inches) of cover, consisting of a natural soil material, should be placed over the fly ash structural fill or embankment. This will act as a kind of thermal insulation. In extreme northern locations, additional cover may be required, but as a general rule 90 centimeters (36 inches) should be sufficient.

• A granular base layer at least 60 centimeters (24 inches) thick may be placed below the fly ash and a minimum cover of three feet of soil aggregate above the fly ash should be required.

• Some states have indicated success with reducing frost susceptibility by blending fly ash with bottom ash or other coarse materials to alter the capillary structure.

• The potential for frost susceptibility may be evaluated in the laboratory by the use of ASTM Standard D 5918-96. This test method involves the compaction of a soil
specimen and then freezing it at one end while free liquid water is in contact with the other end of the specimen. The specimen is subjected to a conditioning cycle and then two freeze-thaw cycles. The specimen is measured for heave and then it is tested for California Bearing Ratio after freeze-thaw cycling. The California Bearing Ratio value is compared with a control test where the specimen is not subjected to freeze-thaw.

**DOT Experiences with and Requirements for Use of Fly Ash in Embankments**

DelDOT requires that a fly ash embankment be built on a foundation that consists of 30 centimeters (12 inches) of washed sand and a minimum of 60 centimeters (24 inches) of traditional borrow material. This layered structure serves the purpose of breaking the capillary system as well as being a drainage foundation for the embankment. The Illinois Department of Transportation (IDOT), in its special provisions for the use of coal combustion by-products as embankment in an on-going airport project, requires that a protective clay liner 90 centimeters (36 inches) thick be placed below the fly ash layer, and above this layer place a 1.5 millimeter (60-mil) polyvinyl chloride geomembrane. Progressing upward, a 30 centimeter (12 inch) thick sand blanket is placed. IDOT also requires that the fly ash embankment be covered with a 60 centimeter (2 foot) layer of clay. The IDOT system prevents frost from penetrating into the fly ash, it prevents capillary movement of water upward through the fly ash, and it prevents the percolation of water into or out of the fly ash. IDOT’s specifications are primarily intended to prevent leachate generation and migration. When IDOT anticipates that frost heaving may be a problem on a project where coal combustion by-products or other materials are used, it requires that 60 centimeters (2 feet) of cover be placed. This cover should have a plasticity index of not less than 12, a liquid limit of less than 50, and a total of silt and fine sand content not more than 65 percent.

The Ohio Department of Transportation specifies the containment of the fly ash embankment core with a 2.5 meter (8 foot) thick layer of natural soil above the fly ash core. A drainage system is also required at the base of the embankment. The lateral containment and overburden layer are intended to prevent frost penetration into the fly ash embankment.

MDSHA requires that a one meter (three foot) thick filter layer be placed below the fly ash embankment. A one meter (three foot) thick cover layer of soil aggregate is then placed over the fly ash embankment. This overlayment may include all pavement components.

NCDOT prevents frost penetration into the embankment by requiring a 30 centimeter (12 inch) cover be placed over the fly ash with an additional 15 centimeters (6 inches) of topsoil on the slopes. This totals 45 centimeters (18 inches) of frost protection. These layers also provide erosion control and a medium for plant growth.

The Virginia Department of Transportation (VDOT) requires that a 30 centimeter (12 inch) thick layer of free-draining material be placed in the footprint of the fly ash embankment. VDOT requires that this material contain no more than ten percent by mass passing the 75 Fm (No. 200) sieve. This layer acts as an open-graded layer that breaks the capillary flow of water upward into the fly ash embankment. VDOT also requires that a soil material be the final 30 centimeters (12 inches) of material placed on slopes.
Two states (Maryland and North Carolina) have established specifications for the use of fly ash in structural fill or embankment applications. Neither of these states establishes any requirement for gradation. Most localities specify a maximum size limit for embankment material, e.g., ten centimeters (four inches). Due to its fine nature, fly ash can always be expected to comply with such a top size specification. There are several jurisdictions that permit the blending of fly ash with other materials (e.g., coal combustion bottom ash) prior to use and other jurisdictions that restrict blending. DelDOT does not permit the mixing of fly ash and bottom ash for structural fill and embankment applications. MDSHA and NCDOT do not permit the mixing of fly ash and bottom ash for structural fill and embankment applications. Fly ash alone is the only material permitted to be used.

The loss on ignition (LOI) test is a measure of the amount of unburned carbon that is present in the fly ash. While there are rigid limitations when fly ash is used as an admixture in Portland cement concrete, such limitations need not be as demanding when fly ash is used as a structural fill or embankment material. One state (Illinois) was found to limit the LOI content of fly ash used in embankments. The AASHTO spec limits LOI content to ten percent.

Due to the chemistry of some fly ash materials, the pH of aqueous solutions that pass through a fly ash structural fill or embankment could induce corrosive conditions. Drainage and utility structures in the vicinity of such a structural fill or embankment are of particular concern. Reinforced concrete and metal culvert pipe may be reactive in low or high pH environments. The Virginia Department of Transportation places some limits on corrosive potential of fly ash and defines such limitations in terms of pH. VDOT limits the pH of fly ash to a range of from 5 to 9.

**Foundry Sand**

Recycled foundry sand (RFS) or Waste Foundry Sand (WFS) is high quality silica sand with uniform physical characteristics. It is a byproduct of the ferrous and nonferrous metal casting industry, where sand has been used for centuries as a molding material because of its thermal conductivity. In modern foundry practice, sand is typically recycled and reused through many production cycles. The automotive industry and its suppliers are the primary generators of this material. The presence of heavy metals is of greater concern in nonferrous foundry sands. WFS generated from brass or bronze foundries may contain high concentrations of cadmium, lead, copper, nickel, and zinc. RFS grain size distribution is more uniform and somewhat finer than conventional concrete sand. The fineness of this substance contributes to good suspension limiting segregation in flowable fills, which are manmade self-leveling, self-compacting backfills. The material displays favorable durability characteristics with resistance to weathering in bituminous concrete paving applications; however, the high amount of silica found in this material may result in stripping of the asphalt cement coating aggregate, which contributes to pavement deterioration. Foundry sand can replace as much as 15 percent of fine aggregates in asphalt concrete and as much as 45 of the fine aggregate in concrete (though green sand can replace only 9 to 15 percent of the fine aggregate), a percentage which industry says can be increased if the foundry sand is processed and fines are removed. Purdue University conducted a study with bituminous concrete samples containing up to 30 percent WFS; this study concluded that including more than
15 percent WFS lowered the unit weight, increased air voids, decreased the flow and stability of the mixes, and reduced the indirect tensile strength.\textsuperscript{cvii}

Foundry sands have also been used as structural fills in highway embankments and sub-grade projects. The specifications for using foundry sands as fill materials generally have been the same as the specifications for typical backfills. These specifications are universal and vary depending on the use of the material, i.e. embankment, structural fill, roadway sub-base, and foundation sub-base, and consist of compacting the material in layers to a minimum percentage of the maximum dry unit weight. The material should also be compacted to a minimum unit weight of 14.9 kN/m\(^3\) (95 pcf) and at a water content around optimum water content. Most specifications require a maximum liquid limit of 65 percent, and a plasticity index less than the liquid limit minus 30. Most foundry sands satisfy these requirements and therefore are eligible to be considered as construction fill materials. Foundry sand has also been studied for use in flowable fills.

\textbf{Glass Aggregate/Cullet}

Glass makes up approximately 7 percent (approximately 12 million tons) of the total weight of U.S. municipal solid waste discarded annually; approximately 20 percent of this glass is being recycled, primarily for cullet in glass manufacturing.\textsuperscript{cviii} Recycling efforts around the country have led to large quantities of broken glass aggregate, or cullet, in many areas that finds few uses due to mixing of colors and high transport costs. The material’s density and color is not an obstacle for use in the transportation industry though. The ability to use glass in highway construction depends on the types of collection methods used, costs, and public factors. In general, the large quantities of waste glass needed for such application are found only in major metropolitan areas. When glass is properly crushed, glass cullet exhibits coefficient of permeability similar to coarse sand. Also, the high angularity of this material, compared to rounded sand, may enhance the stability of asphalt mixes. In general, glass is known for its heat retention properties, which can help decrease the depth of frost penetration. Recycled waste glass can increase the strength, durability and aesthetic appearance of concrete products. Harmful expansion can occur when alkali in the cement paste reacts with the silica in the glass, but technical research has led to ways to suppress the detrimental effects of alkali-silica reaction. While use of glass may not be cheaper unless a ready supply is available nearby, glass is durable, abrasion resistant, improves the flow properties of fresh concrete so that very high strengths can be obtained and can serve both as partial cement replacement and filler.\textsuperscript{cix}

AASHTO’s \textbf{Final Glass Cullet specification - Designation: M 318-01} recommends the following practices in use of glass cullet for soil aggregate base course. (30)

- The engineer should provide appropriate construction specifications to ensure that sufficient compaction is achieved so that further densification of the completed pavement from traffic loadings will be insignificant. The method requires compaction of the material at a suitable moisture content on a firm foundation of a short control strip by means of vibratory or other proven effective rollers or tampers, until no further increase in density results. Compaction requirements should ensure that the average density of the final base course is an appropriate percentage of the maximum density obtained for the control strip; for base
courses, achieving on average 98 percent of the maximum control strip density is suggested.

- The DOT should reference the AASHTO specification, grading to be furnished for the granular base, percentage of glass cullet by mass in the granular base, the optimum moisture content and maximum density of the granular base, and exceptions or additions to the specification.

- The glass cullet should consist of broken food and beverage containers. China dishes, ceramics, or plate glass should be limited to a maximum of 5 percent by mass of glass cullet. Container tops, paper, labels, food residue, foil, wood and other deleterious materials should be limited to a maximum of 1 percent by mass of the glass cullet of which no more than 0.05 percent by mass of paper should be permitted. Extraneous soil-like materials should be limited to a maximum of 2 percent by mass of the glass cullet. Methods to determine these are discussed in the AASHTO spec. Glass cullet should be free of TV or other cathode ray tubes, fluorescent light bulbs, and any toxic or hazardous materials as defined by the state or local jurisdiction.

- Glass cullet should be crushed and screened if necessary so that 100 percent of the glass cullet material passes the 9.5 mm (3/8 in.) sieve. Glass cullet should be free of odor.

- Glass cullet material should be processed so as to limit the quantity of shard-like particles to less than 1 percent by mass as measured by ASTM Standard D 4791, Flat and Elongated Particles in Coarse Aggregate.

- Glass cullet should be combined with soil-aggregate material to form a blended material conforming to the requirements of AASHTO Standard M 147, ASTM D 2940, or the requirements of the specifying jurisdiction.

- The supplier should be permitted to use up to 20 percent by mass of glass cullet in composite glass cullet/soil-aggregate mixtures. If the engineer wishes to use a combination of materials that exceeds the glass percentage limit indicated above, then reference should be made to the evaluation methods described in the AASHTO spec.

- The supplier should ensure that composite material is uniformly blended.

- Glass cullet soil-aggregate composite should be sampled and tested in accordance with standard methods of the American Association of State Highway and Transportation Officials.

**DOT Experiences with Glasphalt and Glass Aggregate**

In bituminous pavements, glass bonds poorly to the asphalt, which can result in stripping and raveling problems. Glasphalt is a new road building material that consists of 30 percent recycled waste glass that has been used in several road maintenance projects in the United Kingdom. Glasphalt is a base-course material that forms part of the structure of the road beneath the surface or wearing course. Trials have shown that glasphalt matches the properties of other sub-base systems when mixed with crushed limestone. Glasphalt can be produced using standard asphalt methods and laid using conventional methods.
equipment, and has the advantage of remaining workable longer than traditional asphalt.\textsuperscript{(cxi)}

Glass aggregate has been investigated by a number of state DOTs including New York, Washington, Pennsylvania, and Texas. Since the 1960s, Washington DOT (WSDOT) has used a portion of glass aggregate in bituminous concrete pavements. This aggregate material is also used in backfill for foundations, pipe bedding, and other applications not subject to heavy repeated loading. WSDOT has not utilized this material on any recent projects. NYSDOT uses a limited amount of this material in embankments and bituminous concrete base and binder courses. This is a non-surface mix material because of concerns that it could result in injury claim liability. NYSDOT has experienced problems with stripping asphalt binder not adhering to aggregate that may be controlled by adding an anti-stripping agent, which in turn adds costs. Pennsylvania DOT also allows a portion of this material in nonstructural fills and drainage applications, while experimentation with this material in bituminous concrete has yielded results similar to New York’s.

New Jersey Department of Transportation (NJDOT) specifications has allowed the substitution of up to ten percent glass (by weight) for aggregate in asphalt base courses. In 1992, the department placed two sections of asphalt surface courses of about 0.5 kilometers (0.3 miles) each containing ten percent glass. One of the sections contained an anti-strip additive; the other did not. Results to date indicate that both of these sections are performing as well as conventional pavement. The Clean Washington Center of Seattle, Wash., has conducted laboratory tests on glass cullet for compaction, durability, gradation, permeability, shear strength, specific gravity, thermal conductivity, and workability as a construction aggregate. The center has subsequently developed recommendations for the approximate percentages of glass to be used for different applications.\textsuperscript{(cxii)}

Several agencies are routinely using recycled glass in the manufacture of glass beads for traffic control devices, and now the material is being used in filtration as well. NYSDOT has used crushed glass (3/8” to 5/8” – See NYSDOT Spec 17605.13 M - Crushed Glass Water and Stormwater Pollution Control Filter) as a Pre-filter to fabric in a filtration system to remove hydro-demolition waste material.\textsuperscript{(cxiii)} At a cost of approximately $4.00/ton for glass, compared to approximately $20/ton for sand, glass has provided a lighter and easier medium for the contractor to handle, a higher porosity (ten seconds per inch) than common sand, and the ability to backfill post-filtration material as “Exempt C&D” waste.\textsuperscript{(cxiv)} Most importantly for the environment, the filtration method reduced Total Suspended Solids (TSS) from 2800 mg/L to 150 mg/L, a removal rate of 96 percent, while reducing pH from 12.0 to 11.8 Std units.\textsuperscript{(cxv)} Finally, crushed glass material is readily available in the vicinity of recycling facilities.

Mass Highway’s specifications for processed glass aggregate require the material to consist of recycled glass food or beverage containers free of debris and manufactured from an approved supplier of crushed cullet, \textsuperscript{(cxvi)} (M2.01.8), and stipulate that glass cullet:

- May be homogeneously blended with Ordinary Borrow material up to an addition rate of ten percent by mass in unexposed areas. \textsuperscript{(cxvii)} (M1.01.0)
• May be homogeneously blended with *Special Borrow* material up to an addition rate of ten percent by mass in unexposed areas. ([cxviii] (M1.02.0)

• May be homogeneously blended with *Gravel Borrow* material up to an addition rate of ten percent by mass in unexposed areas. ([cxix] (M1.03.0)

• May be homogeneously blended with *Processed Gravel* material for *Subbase* up to an addition rate of ten percent by mass in unexposed areas. ([cxx] (M1.03.1)

• May be homogeneously blended with *Sand Borrow* material up to an addition rate of ten percent by mass in unexposed areas. ([cxxi] (M1.04.0)

• May be homogeneously blended with *Sand Borrow* material for *Subdrains* up to an addition rate of ten percent by mass in unexposed areas. ([cxxii] (M1.04.1)

• May be homogeneously blended with *Dense Graded Crushed Stone* material for *Subbase* up to an addition rate of ten percent by mass in unexposed areas. ([cxxiii] (M2.01.7)

• May be used as *Mineral Aggregate in Class I Bituminous Concrete* at a maximum addition rate of ten percent by mass (in place of RAP). ([cxxiv] (M3.11.00)

TTI’s Study 0-1331, *Use of Glass Cullet in Roadway Construction*, identifies sound engineering and environmental uses of glass cullet in roadway construction and maintenance projects and develops specifications. After conducting literature reviews and identifying uses, disadvantages or obstacles, and costs, TTI performed lab testing to provide information not available from the literature search or to ensure the accuracy of the information found. The TTI research team found glass cullet to be appropriate in the following non-pavement applications, according to the specifications below: ([cxxv])

<table>
<thead>
<tr>
<th>TxDOT Item No.</th>
<th>Application</th>
<th>Percentage of Glass Cullet</th>
</tr>
</thead>
<tbody>
<tr>
<td>132</td>
<td>Embankments</td>
<td>Shall not exceed 20% by weight of the total mix</td>
</tr>
<tr>
<td>247</td>
<td>Flexible Base (Type D)</td>
<td>Shall not exceed 20% by weight of the total mix</td>
</tr>
<tr>
<td>301</td>
<td>Asphalt Antistripping Agents</td>
<td>When cullet is used as an aggregate in asphalt-stabilized bases, lime and some liquid antistripping agents may not perform adequately.</td>
</tr>
<tr>
<td>345</td>
<td>Asphalt Stabilized Base</td>
<td>Shall not exceed 5% of the total weight of the aggregate</td>
</tr>
<tr>
<td>400</td>
<td>Excavation and backfill for structures</td>
<td>a.) Utility bedding material may comprise up to 100%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>b.) Backfill that will support any portion of the roadbed or embankment shall include less than 20%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>c.) Backfill that does not support any portion of the roadbed or embankment may include up to 100%</td>
</tr>
<tr>
<td>423</td>
<td>Retaining Wall</td>
<td>Structural backfill limited to maximum of 20%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Non-structural backfill up to 100%</td>
</tr>
<tr>
<td>556</td>
<td>Pipe Underdrains</td>
<td>Up to 100%</td>
</tr>
<tr>
<td>Other</td>
<td>Open-graded Base Courses</td>
<td>The use of cullet in this application shall be governed by Item 345, “Asphalt Stabilized Base.” Not to exceed 5%.</td>
</tr>
</tbody>
</table>

Table 2: Non-Pavement Applications for Glass Cullet - TxDOT/TTI
Other non-pavement applications for glass cullet have included use of glass cullet in filtration basins at NYSDOT and in mulch in a pilot at Caltrans.\textsuperscript{cxxvi} FHWA’s guide for waste glass recycling discusses Asphalt Concrete Aggregate and Granular Base or Fill applications and is available at the Turner Fairbanks Highway Research Center recycling site.\textsuperscript{cxxvii}

**Steel Slag**

Steel slag, a by-product of steel making, is produced during the separation of the molten steel from impurities in steel-making furnaces. The slag occurs as a molten liquid melt and is a complex solution of silicates and oxides that solidifies upon cooling. Virtually all steel is now made in integrated steel plants using a version of the basic oxygen process or in specialty steel plants (mini-mills) using an electric arc furnace process. Steel slag has sufficient material properties including favorable frictional properties, high stability, and resistance to stripping and rutting. In general, processed (i.e. crushed) steel slag is more angular, more dense and harder than comparable natural aggregates.\textsuperscript{cxxviii} Consequently, steel slag has been considered as an aggregate for use in granular base, embankments, engineered fill, highway shoulders, and hot mix asphalt pavement.

FHWA advises that prior to its use as a construction aggregate material, steel slag must be crushed and screened to meet the specified gradation requirements for the particular application. It is primarily used as a coarse aggregate for use in high-type bituminous concrete mixes and seal coats. The slag processor may also be required to satisfy moisture content criteria (e.g., limit the amount of moisture in the steel slag aggregate prior to shipment to a hot mix asphalt plant) and to adopt material handling (processing and stockpiling) practices similar to those used in the conventional aggregates industry to avoid potential segregation. In addition, expansion due to hydration reactions should be addressed prior to use.\textsuperscript{cxxix}

**Scrap Iron Use for Steel Reinforcement**

Scrap iron for steel reinforcement comes from salvaged automobiles, appliances, and steel-reinforced structures which include reinforced concrete pavements, bridges, and buildings. Tons of steel and aluminum scrap recovered from guardrails, sign posts and signs from DOT construction projects are auctioned off to metal scrap dealers each year. The steel industry currently utilizes steel scrap to make structural shapes and plates at the rate of 95 percent and to make steel reinforcing bars at the rate of 47.5 percent.\textsuperscript{cxxx}

Two common forms of steel production are the basic oxygen and electric arc processes. In the electric arc process, “cold” ferrous material, which is generally 100 percent scrap steel, is the major component melted with alloys in an electric furnace. In the basic oxygen process, molten iron is removed from the blast furnace, combined with alloys, and up to 30 percent steel scrap-used as an additive to lower the temperature of the molten composition. In both processes, high-pressure oxygen is blown into the furnace causing a chemical reaction that separates the molten steel and impurities, which can be recycled as slag \textsuperscript{(cxxxi)(cxxxii)}
Steel reinforcement plays an important role in concrete structures; for example, reinforcing in PCC pavements holds cracks together ensuring that high aggregate interlock exists across the pavement. Steel reinforcement is used to strengthen concrete structures, such as reinforced PCC pavements and bridge decks. Two types of commonly used reinforced concrete pavements are jointed reinforced concrete (JRC) and continuously reinforced concrete (CRC). JRC pavements utilize welded wire fabric, while CRC consists of overlapping longitudinal and transverse reinforced steel bars.(

While steel scrap iron is usually recycled, finding alternatives to minimize use also saves on resource consumption and disposal costs, and in the case of guardrail repair times and costs as well. Colorado DOT is replacing some sections of guardrail with wire rope safety fence (WRSF), which has the lowest life cycle costs of any barrier examined and notably improves safety, here measured as driver ability to walk or drive away from accidents. When the WRSF is impacted, usually only a few posts are damaged and must be replaced. In the case of guardrail, posts and long sections of guardrail have to be replaced. While steel can be recycled the fact that much less needs to be replaced with WRSF is a real benefit. Repairs required for vehicles that impact the WRSF are significantly less than other types of safety barriers. Furthermore, during repair, guardrail usually requires heavy equipment and a lane closure greatly slowing traffic (fuel and emissions). WRSF can be repaired with one man in a pickup without a lane closure in normally less than 30 minutes. The design allows small animals to pass through, and has been credited with saving many koala bear lives in Australia. Snow plowing is minimized because snow passes through the design instead of drifting up against it. The same benefits apply in desert conditions with blowing sand. WRSF also offers the visual attributes of blending into the surroundings. WRSF can also help minimize the approach slope needed; concrete barrier and guardrail require ten to one approach slopes while WRSF can have six to one slopes, adding a land consumption benefit in some cases.(

**Wet Bottom Ash and Boiler Slag**

Wet-Bottom Boiler Slag (WBBS or “black beauty”) is a by-product of coal burning in wet-bottom boilers. Slag tap boilers burn pulverized coal and retain up to 50 percent of the accumulated ash as slag-the rest being fly ash. Cyclone boilers burn crushed coal, and retain as much as 80 percent as boiler slag. In both cases, the bottom ash is held at the bottom of the furnace in a molten liquid state, hence the name “wet-bottom.” The product is generally a durable material of uniform size that can be blended with other fine aggregates to meet gradation requirements. WBBS has been used most extensively by local governments on lower volume roads as a seal coat aggregate on very low volume highways or as an abrasive mixed with deicing salt. It can also be used as an aggregate in top surface dressing of bituminous surfaces, embankments, trench backfills, sand backfills for underdrains, bedding, porous granular backfills, membrane water proofing, snow and ice control. It has been used in roadway base and subbase applications as well. Bottom ash is a coarse, angular material of porous surface texture and size ranging from fine gravel to fine sand, predominantly sand-sized, composed of silica, alumina, and iron with small amounts of calcium, magnesium, and sulfate. Bottom ash has been used for snow and ice control, as aggregate in lightweight concrete masonry units, and as raw feed...
material for Portland cement. This material has also been utilized as an aggregate in cold mix emulsified asphalt mixes, base or subbase courses, or in shoulder construction, where the gradation and durability requirements are not as critical. West Virginia and Texas researchers conducted a study in which some of the observations made concluded that performance depends on the amount of pyrites and sulfates present. Also, the quality of the material depends upon how the material was stockpiled before use.\textsuperscript{(cxxxv)} FHWA’s recommended uses for wet bottom ash and boiler slag include the following: \textsuperscript{(cxxxvi)}

\textbf{Example 2: Uses of Recycled Bottom Ash and Boiler Slag}

Both bottom ash and boiler slag have been used as fine aggregate substitute in hot mix asphalt wearing surfaces and base courses, and emulsified asphalt cold mix wearing surfaces and base courses. Because of the “popcorn,” clinkerlike low durability nature of some bottom ash particles, bottom ash has been used more frequently in base courses than wearing surfaces. Boiler slag has been used in wearing surfaces, base courses and asphalt surface treatment or seal coat applications. There are no known uses of bottom ash in asphalt surface treatment or seal coat applications.

Screening of oversized particles and blending with other aggregates will typically be required to use bottom ash and boiler slag in paving applications. Pyrites that may be present in the bottom ash should also be removed (with electromagnets) prior to use. Pyrites (iron sulfide) are volumetrically unstable, expansive, and produce a reddish stain when exposed to water over an extended time period.

\textbf{Granular Base (Bottom Ash and Boiler Slag)}

Both bottom ash and boiler slag have occasionally been used as unbound aggregate or granular base material for pavement construction. Bottom ash and boiler slag are considered fine aggregates in this use. To meet required specifications, the bottom ash or slag may need to be blended with other natural aggregates prior to its use as a base or subbase material. Screening or grinding may also be necessary prior to use, particularly for the bottom ash, where large particle sizes, typically greater than 19 mm (3/4 in), are present in the ash.

\textbf{Stabilized Base Aggregate (Bottom Ash and Boiler Slag)}

Bottom ash and boiler slag have been used in stabilized base applications. Stabilized base or subbase mixtures contain a blend of an aggregate and cementitious materials that bind the aggregates, providing the mixture with greater bearing strength. Types of cementitious materials typically used include Portland cement, cement kiln dust, or pozzolans with activators, such as lime, cement kiln dusts, and lime kiln dusts. When constructing a stabilized base using either bottom ash or boiler slag, both moisture control and proper sizing are required. Deleterious materials such as pyrites should also be removed.

\textbf{Embankment or Backfill Material (Mainly Bottom Ash)}

Bottom ash and ponded ash have been used as structural fill materials for the construction of highway embankments and/or the backfilling of abutments, retaining walls, or trenches. These materials may also be used as pipe bedding in lieu of sand or pea gravel. To be suitable for these applications, the bottom ash or ponded ash must be at or reasonably close to its optimum moisture content, free of pyrites and/or “popcorn” like particles, and must be non-corrosive. Reclaimed ponded ash must be stockpiled and adequately dewatered prior to use. Bottom ash may require screening or grinding to remove or reduce oversize materials (greater than 19 mm (3/4 in) in size.

\textbf{Flowable Fill Aggregate (Mainly Bottom Ash)}

Bottom ash has been used as an aggregate material in flowable fill mixes. Ponded ash also has the potential for being reclaimed and used in flowable fill. Since most flowable fill mixes involve the development of comparatively low compressive strength (in order to be able to be excavated at a later time, if necessary), no advance processing of bottom ash or ponded ash is needed. Neither bottom ash nor ponded ash needs to be at any particular moisture content to be used in flowable fill mixes because the amount of water in the mix can be adjusted in order to provide the desired flowability.
Flue Gas Desulfurization (FGD) Waste

Research on the use of Flue Gas Desulfurization (FGD) waste has focused on its use in stabilized road bases and as an embankment material. Research by the Texas Transportation Institute addressed the use of cement-stabilized FGD waste in roadbase construction. The research consisted of placing two 91.4 m (300 ft) experimental sections containing FGD waste stabilized with 7 percent by dry weight of high early strength, high sulfate-resistant Portland cement. To date, no distress related to the FGD waste in either pavement section has been identified. It was also found that the strength of the cement-stabilized FGD increased when mixed with coal bottom ash. Additionally, surface water and soil leachate were analyzed for both sections; the material constituents were compared with EPA drinking water standards and TCLP concentrations. The results showed that none of the EPA heavy metal concentrations were exceeded. However, the drinking water standards were exceeded for sulfates; TCLP standards do not contain values for sulfate levels.

Tire/Rubber Scraps

Approximately 280 million tires are discarded each year in the U.S., approximately one per person, only 15 million of which are converted to crumb rubber. Around 30 million of these tires are retreaded or reused, leaving roughly 250 million scrap tires to be managed annually. In addition, it has been estimated that there may be as many as 2 to 3 billion tires that have accumulated over the years and are contained in numerous stockpiles.

In addition to tires produced by the general public, tires are a significant waste stream produced by DOTs in the operation and maintenance of hundreds of vehicles. Beside resource depletion (tropical forests) and tire disposal concerns, waste tires have the potential to create a variety of health and safety hazards: tire fires are very difficult to extinguish and stockpiles of waste tires are prime breeding habitats for certain rodents and insects.

A number of DOTs have been contributing to tire recycling efforts. As one example, Indiana DOT (INDOT) is collecting tires at facilities for pickup by a private company that grinds them into small pieces and incorporates them in playground cover, walking trails, running tracks and horse arena covering. In the two years that the program has been in operation, INDOT has diverted well over 20,000 tires of varying sizes from Indiana landfills. Scrap tires, tire pieces that are collected off of the state roads and highways by INDOT maintenance crews are stored in roll-off containers and are taken to landfills where they are utilized in the construction of leachate collection systems and daily cover to aid in drainage. In the past two years, INDOT has recovered and diverted approximately 650 tons of scrap tires from Indiana highways and State Roads.

Asphalt Rubber/Rubber Pavements

The benefits of asphalt rubber use include reduced reflective cracking, traffic noise, design thickness, life cycle costs, increased fatigue life, and resistance to rutting. Asphalt Rubber Hot Mix Gap Graded Specification, is the most popular mix used by agencies in the U.S. Asphalt-Rubber is a mixture of 80 percent hot paving grade asphalt and 20 percent ground tire rubber.
FHWA notes the following applications for ground rubber as an aggregate substitute and as an asphalt modifier: (cxlii)

- **Aggregate Substitute -** Ground Rubber has been used as a fine aggregate substitute in asphalt pavements. In this process, ground rubber particles are added into the hot mix as a fine aggregate in a gap-graded friction course type of mixture. This process, commonly referred to as the dry process, typically uses ground rubber particles ranging from approximately 6.4 mm (1/4 in) down to 0.85 mm (No. 20 sieve). Asphalt mixes in which ground rubber particles are added as a portion of the fine aggregate are referred to as rubberized asphalt.

- **Asphalt Modifier -** Crumb Rubber can be used to modify the asphalt binder (e.g., increase its viscosity) in a process in which the rubber is blended with asphalt binder (usually in the range of 18 to 25 percent rubber). This process, commonly referred to as the wet process, blends and partially reacts crumb rubber with asphalt cement at high temperatures to produce a rubberized asphalt binder. Most of the wet processes require crumb rubber particles between 0.6 mm (No. 30 sieve) and 0.15 mm (No. 100 sieve) in size. The modified binder is commonly referred to as asphalt-rubber.

- **Asphalt-rubber binders** are used primarily in hot mix asphalt paving, but are also used in seal coat applications as a stress absorbing membrane (SAM), a stress absorbing membrane interlayer (SAMI), or as a membrane sealant without any aggregate.

After a surge of interest in the early 1990s, partially related to ISTEA mandates, FHWA and RMRC undertook research projects to resolve specific issues. To address problems states experienced in preparing pavements using the crumb rubber modified asphalt binder, including settling of rubber particles during heated binder storage and raveling of pavements that included crumb rubber modified asphalt (CRMA), FHWA’s Turner-Fairbank Highway Research Center developed a chemically modified crumb rubber asphalt (CMCRA) that not only eliminates the problem of rubber particles settling while in storage but also expands the useful temperature range of the binder. The latter is particularly important because producers generally improve the low-temperature performance of a binder by using a petroleum distillate that is not “cut” so deeply to produce asphalt during the distillation process. This makes the asphalt softer, but it also requires that needed heating or motor oil distillates be left in the asphalt fraction, something that is both economically and ecologically undesirable. By using chemically modified crumb rubber to improve the low-temperature rheological performance of CMCRA made from regular asphalts, FHWA estimated that refiners potentially can save millions of dollars; savings that inevitably make CMCRA a more attractive product to users. Although production of CMCRA is approximately 60 percent more expensive than conventional crumb rubber asphalt, the additional costs are offset by longer pavement life. (cxliii)

In addition to FHWA’s [User Guidelines for Waste and Byproduct Materials in Highway Construction](http://www.fhwa.dot.gov/publications/infrastructure/highway_guidelines.pdf), available from its Turner-Fairbank Highway Research Center, other resources available on-line include:

- The [Rubber Pavement Association](http://www.rubberpavements.org) maintains a current research library with many downloadable documents.

Chapter 5: Pavement, Materials, and Recycling
• Arizona DOT has established a web page Quiet Pavements Pilot Program.
• Recycled Materials Research Center operates a website that includes substantial information on waste tires and other materials in pavements.
• Rubber Manufacturers Association website has a section on scrap tires, with links to suppliers for purchase.
• Rubberized Asphalt Concrete Technology Center is a cooperative effort by the County of Los Angeles, County of Sacramento and the California Integrated Waste Management Board to promote the use of crumb rubber from scrap tires in roadway rehabilitation projects by providing education, training and consultation services to local agencies. The center has an online field inspection guide, asphalt rubber design and construction guidelines, a report on the status of rubberized asphalt traffic noise reduction in Sacramento County, and an asphalt rubber overlay noise study update.
• Asphalt Rubber Design and Construction Guidelines
• An AR overview and table of contents for the design guide can be viewed online, as well as more detailed instructions in the appendices.
• Sacramento County Specification for Asphalt Rubber Hot Mix-Gap Graded (ARHM-GG) is also available on-line
• Better Roads published an in-depth look at Open Grade Friction Courses, called A New Era for Permeable Pavements, April 2003, pp 28-32.

State DOT Experience with Recycling and Use of Recycled Rubber Products
The Oregon Department of Transportation (ODOT) has been monitoring performance of seventeen rubber modified asphalt and asphalt concrete sections constructed on Oregon highways. After five years, the PBA-6GR pavements were performing as well or better than the control sections.(cxliv)
The remaining examples are summarized from those available at the Rubber Pavement Association.(cxlv) More examples are available there and will be available soon as a result of quiet pavement research by FHWA, Caltrans, ADOT, and the USDOT Volpe Research Center.(cxlv) NCHRP Project 1-44, Quiet Pavement Pilot Project Study will begin in 2005.

Arizona DOT Asphalt Rubber Projects
In 1990, the Arizona Department of Transportation designed and constructed a large scale Asphalt-Rubber (AR) test project in Flagstaff, Arizona on the I-40, where 1999 traffic exceeded 20,000 vehicles per day with 35 percent large trucks. The purpose of the test project was to determine whether a relatively thin overlay with AR could reduce reflective cracking. The overlay project was built on top of a badly cracked concrete pavement, constructed in 1969 and exhibiting signs of failure by 1974, for which ADOT maintenance spent approximately $80,000 per year trying to hold the pavement together. By 1988 reconstruction, at a cost estimated to be at least $30 million, appeared to be the only option. Due to money and time constraints, the project could not be reconstructed and various overlay strategies were considered, including many different overlay thicknesses, use of a fabric interlayer, asphalt-rubber interlayer, various mixes, edge
drains and cracking and seating. ADOT selected an AR binder to test whether a relatively thin pavement overlay could control reflective cracking. The design section included edge drains, crack and seat the concrete Pavement, a five inch overlay consisting of a three inch conventional dense hot mix asphalt, a two inch gap graded asphalt-rubber mix (AR-AC) with a 6.5 percent binder and a one-half inch AR OGFC with a 9 percent binder content. The design was for ten years, but all involved in the project considered it would last six years given the thin overlay design and the poor condition of the concrete. As of evaluation at nine years of service, the Asphalt-Rubber overlay was virtually crack free, with good ride, virtually no rutting or maintenance and good skid resistance. The use of AR on the project saved about $18 million dollars in construction savings and four years less construction time, and led to a new specification and widespread use of Asphalt-Rubber hot mixes throughout Arizona. Arizona Department of Transportation used approximately 14 million tires between 1988 and 2002. The agency estimates 40 percent of its 7,500 mile highway system is surfaced with AR.

**Colorado DOT Rubber Asphalt Experience**

The state of Colorado, based on the cold weather performance in northern Arizona placed an Asphalt-Rubber Chip Seal in June 2003. In a final construction report issued by the CDOT Aeronautics Division, the agency said, “the validity of rubber asphalt paving materials had been proven by our sister states of California and Arizona, which rely heavily on the process to provide a significant increase in the longevity of the pavement and the wise recycling of used auto tire products. Reflective cracking has all but been eliminated with the process and the pavement remains flexible and viable long after non rubberized materials have failed. In the past, the acute stresses placed on pavements at high altitude Colorado locations have made it necessary to rehabilitate airport movement areas every two to three years. It is anticipated that the introduction of the rubber asphalt materials will extend the life of the pavements for seven to ten years.”

**Nebraska Department of Roads Asphalt-Rubber Project**

The Nebraska Department of Roads placed its first Asphalt-Rubber project in September 2001 on Highway 2 near Lincoln. The project consisted of a 1/2 inch to 11/2 inch SP5 leveling course and a 2 inch Asphalt-Rubber gap graded mix over a heavily deteriorated concrete pavement that was milled 3/4 inch. January temperatures range from a high of 32F to lows of 10F. Summer temperatures go up to 104F. Since the Highway 2, NDOR has placed Asphalt-Rubber projects on Interstate 80 and Highway 14. According the NDOR Materials Engineer, Robert Rea, the projects are performing well. NDOR, which researched Asphalt-Rubber for three years prior to its first project, is planning an AR OGFC with lower voids and a higher binder content as one of its two upcoming projects.

**Maine DOT Use of Tire Chips in Road Base**

A 1992 project in Richmond, Maine, assessed the effectiveness of using tire chips as an insulating layer in order to limit frost penetration beneath a gravel-surfaced road that experienced severe deterioration during spring thawing. Thermocouples, resistivity gauges, groundwater monitoring wells, and a weather station were installed to monitor
After a year, results indicated that a 152-mm-thick tire chip layer can reduce frost penetration by up to 40 percent.

**Embankment and Retaining Wall Construction**

Shredded or chipped tires have been used as a lightweight fill material for construction of embankments. However, combustion problems at three locations have prompted a reevaluation of design techniques when shredded or chipped tires are used in embankment construction. Although not a direct highway application, whole tires have been used to construct retaining walls. They have also been used to stabilize roadside shoulder areas and provide channel slope protection. For each application, whole tires are stacked vertically on top of each other. Adjacent tires are then clipped together horizontally and metal posts are driven vertically through the tire openings and anchored into the underlying earth as necessary to provide lateral support and prevent later displacement. As initially performed in California, each layer of tires is then filled with compacted earth backfill. Slit scrap tires can be used as reinforcement in embankments and tied-back anchor retaining walls. By placing tire sidewalls in interconnected strips or mats and taking advantage of the extremely high tensile strength of the sidewalls, embankments can be stabilized in accordance with the reinforced earth principles. Sidewalls are held together by means of metal clips when reinforcing embankments, or by a cross-arm anchor bar assembly when used to anchor retaining walls. Studies on placement of tires in embankments have shown reduced water quality where ponding can occur; however thermal stability tests found shreds are stable up to temperatures of 200 C, indicating that other mechanisms may be attributed to the exothermic reactions, which occurred in tire fills.

Mass Highway is undertaking a two-year study of the performance of tire shreds as mitigation for secondary compression of organic soils beneath a roadway embankment. Two projects, one using 250,000 tires and one using 750,000 tires will use shreds of 2-6 inches in size to reconstruct an embankment underlain by unsuitable organic soils. The embankment has been designed to test pavement performance over a soil cover thickness of two feet. Mass Highway has another project to test water quality in relation to use of Tire Shreds as Lightweight Fill Below Groundwater. NCDOT used scrap chipped tires as embankment fill material in two recent projects - one in Davidson County (1,279,000 tires) and another in Catawba County (1,151,077 tires).

A Carson City, Nev., company is marketing a noise wall that contains recycled rubber tires and recycled plastics. The wall’s shell is made of a composite of polyester and glass, and the fill section is made of ground, recycled plastics and rubber tires.

**Rubber Spacer Blocks in Crash Barriers**

An Evaluation of Recycled Rubber Spacer Blocks is being funded through an RMRC Technical Problem Solving grant. Iowa DOT would like to use spacer blocks made from recycled tires in their crash barriers. However, FHWA needs data to support the use of such hardware on the National Highway System, following the criteria for testing safety hardware defined in National Cooperative Research Program (NCHRP) Report 350, which includes crash testing. FHWA drafted a Letter of Acceptance for Recycled
Spacer Blocks. (cli) Test results in 12 Midwest states (cliii) will be available soon, as will Iowa DOT specifications for recycled tire spacer blocks. (cliv)

**Rubber Buffings for Bridge Approach Expansion Joints**

Iowa DOT is also exploring techniques for filling expansion joints by stuffing the gaps with shaved tired particles, instead of foam blocks. Foam blocks had trouble during bridge expansion and contracting and with heavy rains floating them out of joints. Iowa DOT tested the rubber material for density, gradation, compression and rebound qualities, foreign material content, and compatibility with several types of sealant. At the end of the testing, one combination of buffings and sealant performed better than the rest, so that one was recommended back to the bridge crews. Details of the testing were published in the October 2001 Final Report MLR-01-1 “Rubber Buffings for Bridge Approach Expansion Joints.” Field testing on repairs of expansion joints began last year with excellent results: the tire buffings will not deteriorate over time because they are heavier than water and won’t float away in a strong rain; nor do they pose a significant hazard on the roadway. The cost is less than half the cost of the foam blocks currently specified for these joints. The new standards for use of tire buffings in expansion joints were included in the Road Design Standard update. (clv)

**Rubber Tires to Control Vegetation around Guardrails and Signposts**

Anti-vegetation tile are designed to prevent grass and weeds from growing up and around guard rails, fencing, and signs. The 2-ft. x 2-ft. tiles are made from ground-up rubber tires and offer durability, ease of installation and ten years or more of maintenance-free service. They can improve driver sight distance and reduce the need for herbicides and trimming. Anti-vegetation tiles also have a low profile, which keeps them out of the way of a mower blade. Each tile has universal guides scribed on the bottom so they can be easily cut to fit around a post. (clvi)

The Texas Department of Transportation (TxDOT) is installing and evaluating tiles made from tire rubber to control vegetation around guardrails and sign posts in several TxDOT districts. District staff will evaluate the ease and cost of their installation and their long-term performance in diverse climate conditions. The project will also compare life-cycle costs of the tiles to other TxDOT vegetation control systems. The sites’ diverse climate and terrain is expected to make the project’s findings useful across the United States. If accepted for use in new construction, retrofits, and maintenance to control vegetation, tire-rubber tiles for guardrail and sign posts could consume more than the 500,000 tires’ worth of rubber TxDOT operations generate each year. (clvii)

**Rubber Posts for Traffic Delineation and Channelization**

The Wyoming Department of Transportation uses RubberTough posts in highway stretches plagued by severe weather and low visibility. Made of recycled tires that can snap back because of a patented swing hinge made of rubber, the posts bend but don’t break, reducing costs. The posts are secured into the ground via a steel spike and are used mainly for delineation and channelization. (clviii)
**Plastics**

Plastics comprise more than 11 percent of the total weight of the municipal waste stream and about 12 to 20 percent of its volume; only 5 percent is recovered. Recycled plastic has been used for items such as guardrail posts and block-outs, delineator posts, fence posts, noise barriers, sign posts, and snow poles. The Federal Highway Administration has approved the use of a guardrail offset block made of 100-percent recycled wood and plastic. Although the product’s initial cost is currently higher than for conventional block material, it is believed that the post will resist damage and deterioration better than conventional materials, thereby resulting in reduced overall life-cycle cost.

**Plastics in Asphalt**

Polyethylene has been added to asphaltic concrete for some time; NOVOPHALT and Polyphalt are newer asphalt cement additives that use recycled low-density polyethylene resin which is generally obtained from plastic trash and sandwich bags. The recycled plastic is made into pellets and added to asphalt cement at a rate of 4 to 7 percent by weight of binder (0.25 percent to 0.50 percent by weight of total mix). Base asphalt cement combined with recycled plastic mil bottles, scrap tires, and a paraffinic polymer obtained from coal were found to have a lower viscosity and higher PG than traditional asphalt, allowing successful replacement of traditional Cutbacks using Diesel fuel and Kerosene such as MC 250, 800, 3000. This asphalt mix was successfully used in Germany for chip-seal and crack filling operations using only conventional application equipment.

**Recycled-Plastic Lumber in Noise Barriers, Posts, Guardrails, and Reinforcing Materials**

Recycled-plastic lumber, a material extruded into standard lumber sizes used by the timber industry, has many advantages: it is durable and requires little maintenance, can be cut and fastened like wood, provides several aesthetic alternatives in both color and texture, is highly resistant to insects and graffiti, is readily available, and is thus inexpensive compared to custom-made plastic shapes. Being denser, it blocks noise more effectively than wood sheathing of similar thickness. Increasing public demand for reduced traffic noise levels is also generating a growing need for more and better highway noise barriers. Furthermore, those using conventional materials such as wood, steel, or concrete deplete natural resources and occasionally meet public criticism with respect to aesthetics. Barriers that use recycled plastic thus are not only functional but also environmentally beneficial. A recent TRB paper provides design guidelines for a system competitive with current barriers with respect to initial cost that may have long-term economic benefits because of greater durability, minimal maintenance, and low life-cycle cost.

Static cantilever bending tests have shown that recycled posts are more flexible than conventional wood and steel posts; however, the ultimate load capacities for several recycled posts are comparable to that of conventional posts. Pendulum test results show that the energy absorption of some of the recycled posts is as high as that of conventional wood posts. As a result, the overall performance of recycled posts compares favorably with conventional posts. Studies on the field performance of embankments...
stabilized with recycled plastic reinforcement observed that slopes are performing better than control sections and that the reinforcing members have significant remaining capacity to maintain the stability of the slopes. \((clvii)\)

In 2000, the Chelsea Center for Recycling and Economic Development (part of UMass Lowell) contracted with Mass Highway Sustainable Solutions to develop a Life Cycle Assessment of three types of offset blocks for use by Mass Highway in guardrail systems. The purpose of the project was to provide MHD with basic information and analyses needed to make environmental and cost comparisons between recycled plastic, recycled steel, and pressure treated wood offset blocks over the course of their life spans from manufacture through disposal. The study concluded that while W-beam guardrails constructed with wood offset blocks have the lowest estimated installation cost, those with plastic offset blocks have the lowest estimated net present cost. However, for three-beam systems, wood offset blocks have the lowest estimated net present cost. Additionally, concerns about wood offset blocks were raised, such as drying, cracking, and loss of structural integrity. As a result of this study, MHD published standard specifications for recycled plastic offset blocks in November 2000. \((M8.07.0)(clviii)\)

NCDOT recently installed guardrail on I-95 with 23,283 recycled plastic offset blocks.\((clxix)\)

The Missouri DOT (MoDOT) and the University of Missouri-Columbia started a project in 2002 to develop a plastic soil pin guidance specification for MoDOT for soil nailing. The research will result in a recommendation to AASHTO for a provisional plastic soil pin specification. \((clxx)\)

**Plastics in Piles and Bridge Fenders**

Using recycled plastic fiber-reinforced polymer (FRP) composites as pile material have been found to potentially eliminate deterioration problems of conventional piling materials in waterfront environments and aggressive soils (solutions with fixed acidic, basic, and neutral pH at elevated temperatures).\((clxxi)\)

Caltrans engineers are experimenting with fenders made of recycled plastic and other consumer products that can resist marine borers better than wood and not pose the environmental threat that most wood treatments present. After evaluating different materials, Caltrans found that recycled plastic with fiberglass rebar at the corners or bridge fenders is an acceptable alternative. Although it is twice as expensive as treated wood, initial studies suggest it lasts three times as long.\((clxxii)\)

**Aluminum Sign Recycling and Chromate Coating Elimination**

In North Carolina, aluminum sign recycling is conducted through arrangements between the NCDOT and Department of Corrections. DOC purchased a Hydrostripper that utilizes a high-pressure water system to remove old reflective material from the signs. Because it uses water, the signs are not ground away which allows the aluminum to be used over and over. The most outstanding feature of this method is that the aluminum is not affected during the cleaning process, thereby eliminating the need to reapply the chromate coating.

The Missouri Department of Transportation (MODOT) began their sign reclamation program in 1978. The total cost of the original sign reclamation plant and its operation was $1.1 million. The use of the aluminum sign blanks, which were refinished that year
in lieu of purchasing new aluminum sign blanks, saved MODOT more than the total cost of construction and operation of the reclamation operation. In each year of operation the plant has returned to MODOT than the original cost. The original plant was equipped with a metal sander, a press to straighten damaged blanks, along with a metal shear, which was used to cut away damaged parts of a blank in order to create a smaller sign blank rather than scrapping the damaged sign. In 1997, the reclamation operation was turned over to the Missouri Department of Corrections since they could do the work at an even greater savings to MODOT. Since that time various improvements have been incorporated to enhance the operation. A major change involved switching from a sanding operation to remove the sheeting material to a Hydro-Stripper which performs the cleaning operation. This method has an added advantage of not removing the aluminum coating of chromate that is used to provide better adherence of reflective sheeting or paint. The current cost of reclaiming rather than purchasing new sign blanks is a 75 percent savings. For the larger extruded structural signs the saving is slightly less. The saving to MODOT in 2003 was $3.5 million dollars.\(\text{clxxiii}\)

5.8 Maintenance of Dirt and Gravel Roads

Over 1.6 million miles of unpaved roads (53 percent of all roads) are unpaved. Many of these roads will remain unpaved due to very low traffic volume and/or lack of funds to adequately improve the subgrade and base before applying pavement layer(s). In some countries, economic constraints mean gravel roads are the only type that can be provided. Dirt and gravel roads represent a very small percentage of roadways maintained by state DOTs in almost all cases; counties and federal agencies manage the large majority of the dirt and gravel roads in the United States. Nevertheless, a few state DOTs have become very involved in managing dirt and gravel roads and have developed environmental stewardship practices and partnerships that may be useful for other state DOTs. General practices for pollution prevention from dirt and gravel roads include:

- Stabilize exposed soil areas to prevent soil from eroding during rain events. This is particularly important on steep slopes.
- For roadside areas with exposed soils, the most cost-effective choice is to vegetate the area, preferably with a mulch or binder that will hold the soils in place while the vegetation is establishing. Native vegetation should be used if possible.
- If vegetation cannot be established immediately, apply temporary erosion control mats/blankets; a comma straw, or gravel as appropriate.
- If sediment is already eroded and mobilized in roadside areas, temporary controls should be installed. These may include: sediment control fences, fabric-covered triangular dikes, gravel-filled burlap bags, biobags, or hay bales staked in place.

Partnerships to Identify and Address the Most Pressing Erosion Problem Areas

The Pennsylvania Task Force on Dirt and Gravel Roads is a cooperative effort between PennDOT and several other state and private agencies to improve the environmental quality of Pennsylvania’s streams and waterways. PennDOT started working with Trout Unlimited in the early 1990s to mobilize volunteers to identify sedimentation problem
areas from eroding roads and shoulders and areas of adverse impacts to streams. Initial efforts concentrated on Pennsylvania’s protected watersheds, designated as either High Quality (HQ) or Exceptional Value (EV), and including drinking water reservoirs and cold water fisheries. Trout Unlimited’s volunteer effort culminated in the identification of over 900 sites, which became the basis for the Dirt and Gravel Road Pollution Prevention Program. In 1999-2000, a statewide committee followed up with a statewide inventory and assessment of all 17,000+ miles of Pennsylvania’s dirt and gravel road network. Conducted by County Conservation Districts, this effort identified more than 9600 specific pollution sites impacting more than 3,000 miles of roadway. All 9600+ worksites were mapped, rated (on a 12-step, 100 point scale) and recorded in GIS program files. Top priority in the first three years was given to pollution “trouble spots” identified in watersheds protected as “exceptional value” and “high quality.” As of 2000-01, a new allocation formula was used to distribute funding to affected communities statewide, with verified pollution sites on unpaved roads. Pennsylvania’s 65 Conservation Districts administer the program at the county level with annual allocations from the State Conservation Commission. With the help of a local Quality Assurance Board (QAB), they:

- Work directly with applicants to develop plans for projects
- Assist with logistics of project work whenever possible
- Keep track of records of projects in their County using GIS system
- Develop a prioritization ranking incoming applications through the QAB
- Decide which project will be funded each year, through the QAB, and
- Conduct project inspections after site work is completed

To be eligible to apply for funding, an official form a municipality must attend a free 2-day training on environmentally sensitive maintenance for unpaved roads that explains basic environmental principles and introduces new techniques and ideas in unpaved road maintenance. The Center for Dirt & Gravel Road Studies at Penn State conducts “Environmentally Sensitive Maintenance,” a 2-day course that includes modules on drainage, road maintenance techniques, erosion prevention & sediment control, bank stabilization, roadside vegetation management, and grant procedures.

In assessing progress toward addressing priority erosion control areas statewide, the program tracks:

- Drainage Outlets Stabilized (Sq Ft)
- Eroded Ditch Stabilized (Sq Ft)
- Road Bank Stabilized (Sq Ft)
- Stream Bank Stabilized (Sq Ft)
- Fabric Used (Sq Ft)
- Stream Culverts Replaced (#)
- Cross Pipes Added (#)
- Road Stabilized (Sq Ft)
- Vegetative Management (Sq Ft)
• Length of stream culverts replaced (Ft)
• Length of cross-pipes added/replaced (Ft)

**Tools and Techniques for Erosion Reduction/Prevention**

PennState’s Dirt and Gravel Roads Center provides extensive resources and program information for managing dirt and gravel roads. The Center provides an extensive Dirt & Gravel Roads training program that is available upon request. Technical bulletins available on-line include:

• **Grade Breaks** — Surface drainage features that stop concentrated flow and road erosion.
• **French Mattress** — Method for allowing water to pass under a road through coarse stone.
• **Driving Surface Aggregate** — Details and differences from other aggregates.
• **DSA Specs** — Purchasing and placement specifications for Driving Surface Road Aggregate.
• **Trail Mix Spec** — Purchasing specifications for Trail mix aggregate.
• **Surface Maintenance** — General information on maintaining unpaved roads.
• **Carbide-Tipped Blade** — Details on the benefits of a carbide-tipped blade for surface maintenance operations.
• **Grading Sequence with a Carbide-Tipped Blade** — How-to document detailing a sequence for surface maintenance using a carbide-tipped blade.
• **Crown & Cross-Slope** — Informational document describing different types of crown and proper cross-slope of unpaved roads.
• **Headwalls & Endwalls** — General information of the benefits of headwalls and endwalls at pipe installations.
• **Natural Stone Headwalls** — Details on how to construct headwalls and endwalls of native stone.

The **Center’s list of environmentally acceptable products** for petroleum emulsion dust suppressant, acrylic polymer dust suppressant, road fill materials, soil amendments is also available on-line.

A variety of other technical resources are available from federal agencies, teams, and other states in some instances. The Local Technology Assistance Program maintains a listing which includes the following of potential interest to state DOTs: (clxxiv)

• **Soil Bioengineering - An Alternative for Roadside Management, A Practical Guide from USDA Forest Service San Dimas Technology and Development Center Publications**. The center also has a “Road Maintenance Video Set” five-part video series on environmentally sensitive ways of maintaining low volume roads. (Total Running Time: 1 hour 23 minutes).
• **National Riparian Service Team**
• **Riparian Roads Restoration Team** - Has slide shows (PowerPoints) and engineering applications available on-line.


• **Recommended Practices Manual: A Guideline for Maintenance and Service of Unpaved Roads (EPA)** - Standard procedures describing and illustrating cost-effective techniques and practices which can be used to enhance stability and maintenance of unpaved roadways while reducing sedimentation and improving the quality of surface waters.

• **Best Practices for the Design and Construction of Low Volume Roads** - Presents information about the use of the mechanistic-empirical procedure (MnPAVE) in designing hot-mix asphalt pavements in Minnesota. Researchers developed the MnPAVE software program using information from the Minnesota Road Research Project (Mn/ROAD) test facility and from 40-year-old test sections around Minnesota. MnPAVE procedures use Equivalent Standard Axle Loads (ESALs) to evaluate traffic loading, and the report includes methods to estimate these values for design purposes over a 20-year design life, as well as a procedure to measure vehicle type distributions. Presents an evaluation of subgrade soils for each thickness design procedure, summarizes Minnesota Department of Transportation specifications that relate to embankment soil construction and to construction of the pavement section materials, and recommends specific density or quality compaction using a control strip. Includes best practices on setting up projects most effectively to follow specifications.


South Dakota’s [Gravel Roads Maintenance and Design Manual](#) is a comprehensive manual available in both html and pdf formats that addresses most issues that deal with gravel road maintenance. The practices included in the manual are available via the links below:

**Example 3: South Dakota DOT Gravel Roads Maintenance and Design Manual Sections**

**Section I: Routine Maintenance and Rehabilitation**

- **Understanding Road Cross Section**

- **Routine Shaping Principles**
  - Operating Speed
  - Moldboard Angle
  - Moldboard Pitch
  - Motorgrader Stability
  - Articulation
  - Windrows

- **Crown**

- **Road Shoulder**
  - High Shoulders (Secondary Ditches)
  - Causes of High Shoulders
  - Recovering and Spreading on Roadway

Chapter 5: Pavement, Materials, and Recycling
o Breaking up Sod and Vegetation in Recovered Material
o Pulling and Covering
o Benefit of Mowing

**Gravel Road Rehabilitation**
- Reshaping Surface and Shoulder
- Reshaping Entire Cross Section
- Erosion Control

**Areas of Concern**
- Dealing with Corrugation
- Intersections
- Intersection with Paved Roads
- Bridge Approaches
- Superelevation in Curves
- Rail Crossings
- Driveways
- Cattle Guards
- Soft and Weak Subgrade

**Section II: Drainage**
- Ditches
- Culverts and Bridges
- Underdrains

**Section III: Surface Gravel**

- What is Good Gravel?
  - Difference in Surface Gravel and Other Uses.
  - Good Gradation
  - Benefit of Crushing
  - Recycled Asphalt

- The Benefit of Testing Aggregates
  - Reasons for Testing
  - Sampling
  - Sieve Analysis
  - Fines and Plasticity Index
  - Reduced Blading and Maintenance Costs

- Process for Obtaining Good Gravel
  - Establish Specifications
  - Communicate with Suppliers

- Handling Gravel.
  - Pit/Quarry Operations
  - Loading from Stockpiles
  - Roadway Preparation
  - Calculating Quantity
  - Hauling and Dumping
  - Windrowing, Equalizing and Spreading

**Section IV: Dust Control/Stabilization**

- Types of Stabilizers
  - Chlorides
  - Resins
Natural Clays
Asphalts
Soybean Oil
Other Commercial Binders

Benefits of Stabilization
- Reduced Dusting
- Reduced “Whip Off” of Aggregate
- Reduced Blade Maintenance

Application Tips
- Need for Good Surface Gravel
- Road Preparation
- Applying the Product
- Optimum Moisture
- Test Sections

Section V: Innovations

Changes in Gravel Maintenance
- Changing Conditions—Equipment, Trucks, Cars
- New Innovations

Innovative Equipment and Methods
- Windrow Pulverizers
- New Cutting Edges
- Shouldering Disks
- Grader-Mounted Dozer Blade
- Grader-Mounted Roller.
- Rakes
- Other Tractor-Mounted Blading Devices

Summary

References

Appendix A: Gravel Road Thickness Design Methods
Appendix B: Gradation and P.I. Determination
Appendix C: Quantity Calculations
Appendix D: When To Pave a Gravel Road
Appendix E: Walk-around Grader Inspection


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