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Concrete Pavement Sustainability

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This MAP Brief is based on the January 2012 *Sustainable Concrete Pavements: A Manual of Practice* produced by the National Concrete Pavement Technology Center. The manual provides additional details and information about additional related topics. See www.cptech-center.org/publications/Sustainable_Concrete_Pavement_508.pdf.

Moving Advancements into Practice (MAP) Briefs describe innovative research and promising technologies that can be used now to enhance concrete paving practices. The March-April 2012 MAP brief provides information relevant to Track 12 of the CP Road Map, Concrete Pavement Sustainability.

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"Moving Advancements into Practice"

MAP Brief March-April 2012

Describing promising technologies that can be used now to enhance concrete paving practices

Concrete Pavement Sustainability: State of the Practice

In general, sustainability is the capacity to maintain a process or state of being without exhausting nonrenewable resources or degrading the environment. For practical purposes, infrastructure-related activities (including concrete pavement projects) are considered sustainable insofar as, over their lifetime, they maintain a workable balance among three often-competing interests—economic, environmental, and social—the "triple bottom line" (Elkington 1994).

Focusing on sustainability will help the concrete pavement industry meet increasing public demands and owner-agency requirements, become more innovative and competitive, and attract a younger workforce motivated to choose careers in which they can make a positive difference.

An all-encompassing system for increasing concrete pavement sustainability through measureable metrics does not exist. However, progress can be made by implementing existing and emerging best practices and technologies at every stage of a project.

Design

Decisions at this stage will dramatically affect a project's lifetime sustainability. Design objectives must be integrated with decisions, practices, and limitations in other stages, particularly the materials/mixtures and construction stages. In general, the designer must follow logical guidelines:

- Identify and account for human needs and values beyond a driving platform (e.g., a quiet pavement surface that reflects light/heat may be especially important in an urban environment).
- Choose solutions with minimum economic, environmental, and social cost (and maximum benefits) without compromising engineering quality. *Consider the impact of alternative approaches and conduct sensitivity analyses.*

Triple bottom line of sustainability

- Design for the intended life (likely 40 years or more).
- Design for what is needed. Overdesign is wasteful, but under-design even more so.

Examples of concrete pavement characteristics that contribute to a sustainable pavement design, as appropriate, include the following:

- Smooth pavements that enhance vehicle fuel efficiency.
- Surface texturing for noise reduction and adequate skid resistance.
- Surfaces that reflect light/heat and require less artificial lighting.
- Long life, maximized by appropriate maintenance and renewal activities.
- Reduced work zone–related traffic interruptions or pavement closures due to construction, maintenance, and renewal.
- Storm water runoff management.

Examples of proven systems or technologies for sustainable design include the following:

- *Pervious pavements* – Allow rainwater to percolate through the slab and base, replenishing groundwater rather than draining rainwater to a storm water or effluent system.

- *Interlocking concrete pavers* provide an aesthetically pleasing surface that can also be pervious, reflective, or even photocatalytic for air purification.
- *In-situ concrete recycling* maintains and builds equity in the existing pavement.
- *Precast concrete pavement systems* are fabricated off site in precast plants.
- *Roller-compacted concrete (RCC) pavements* use stiff concrete mixtures placed and densified with equipment typical of hot-mix asphalt construction; appropriate for low-speed, heavy load areas such as commercial delivery areas.
- *Two-lift concrete pavement design* are constructed in two lifts, with the use of higher-end and/or virgin materials restricted to the top lift.

Examples of potential future systems or technologies being studied include the following:

- Smart pavements that monitor their condition and report when they are getting stressed.
- Pavements that generate electricity to power adjacent neighborhoods.
- Systems that capture geothermal heat under the pavement to melt snow and ice.
- Pervious shoulders with bacteria in them that will treat water as it travels through the pavement.

Materials and Mixtures

Durable natural aggregates are becoming scarcer, which can increase their purchase price and, if the aggregate has to be hauled long distances, transportation costs and related greenhouse gas emissions. The use of recycled concrete and other "recovered" materials as aggregate can be a cost-effective and environmentally friendly practice.

Waste water from production operations (returned concrete, truck wash water, etc.) can be clarified through settling ponds, tested for impurities, and recycled into the production process.

Manufacturing portland cement is an energy-intensive process involving heating limestone and shale to form clinker, the primary component of portland cement. Both the burning of fuel for the kiln and the decomposition of limestone release the greenhouse gas calcium dioxide (CO_2).

More environmentally friendly supplementary cementitious materials (SCMs) and/or finely ground limestone can be used in the concrete mixture to supplement (and thus reduce the amount of) portland cement. SCMs can also enhance concrete durability and other characteristics like surface reflectivity, which is a factor in heat retention and night-time visibility/safety.

Examples of current best practices for sustainable concrete materials and mixtures include the following:

Placement of pervious concrete pavement (courtesy of John Kevern, University of Missouri-Kansas City)

Recycled concrete aggregate (courtesy of Jim Grove, FHWA)

Placement of precast concrete pavement (courtesy of Shiraz Tayabji, FHWA)

Two-lift concrete paving (courtesy of Kansas DOT)

- Use of more efficient cement manufacturing processes (dry-processing, more efficient kilns, use of alternative fuels like hazardous wastes, reduced amount of clinker in the cement, and other advancements).
- Reducing portland cement content in concrete mixtures (incorporate SCMS and/or chemical admixtures and reduce overall cementitious materials content).
- Enhancing concrete durability/resistance to de-icing chemicals by optimizing the water-to-cementitious materials (w/cm) ratio (use chemical admixtures and/or optimize aggregate gradation) without sacrificing workability.
- Substitution of recycled concrete for some of the aggregate.
- Use of performance-based, as opposed to prescriptive approaches.

Examples of emerging practices and technologies include the following:

- Innovative fuels that reduce CO_2 emissions and reliance on oil-based fuels.
- Photocatalytic cements that absorb and break down atmospheric pollutants like nitrogen oxides.
- Use of recycled asphalt pavement (RAP) as aggregate in concrete mixtures.

Examples of potential future systems or technologies currently being studied include the following:

- Low-carbon and carbon-sequestering cements.
- Energy-efficient devices to capture CO_2 emissions and convert them to solid carbon fiber.
- Alternative raw materials for portland cement manufacture that will not involve the decomposition of carbonate rock.
- Mixtures that have self-healing capabilities.

Construction

A pavement intended to be sustainable through enhanced design and optimized materials/mixtures can turn out to be non-sustainable due to improper construction processes and/or a lack of quality control leading to premature failure. In addition to direct construction costs, other economic, environmental, and societal impacts associated with the construction stage include the following:

- Type and frequency of future maintenance and renewal activities, with accompanying impacts.
- Energy consumed by and emissions from construction equipment and haul vehicles.
- Erosion and storm water runoff.
- Generation of airborne dust particulates and noise.
- Slurry run-off.
- Traffic delays resulting in increased user costs and inconvenience.

To address such impacts, several best practices should be emphasized:

- Ensure that appropriate equipment is available and in good working order.
- Minimize traffic disruption and maximize project efficiency through convenient plant location, haul road location and maintenance, staging areas, borrow sites, etc.
- Reduce construction-related noise, waste, and disruption of the surrounding area.
- Perform appropriate quality assurance and quality control to ensure specified concrete pavement characteristics.

Renewal

Appropriate, timely pavement renewal (maintenance and rehabilitation) reduces future investment in materials and construction. Renewal helps retain or re-establish desired pavement characteristics, thus extending service life.

In general, maintenance involves preventive maintenance and repair activities. Rehabilitation involves restoring or enhancing structural capacity, generally via unbonded overlays and some bonded overlays.

Concrete overlays are proving to be cost-effective, versatile solutions, as agencies around the country construct demonstration projects. Overlays can increase a pavement's effective service life and/or restore or improve surface characteristics and rideability.

Recycling

At the end of life, a concrete pavement should be completely recycled by breaking and crushing it into recycled concrete aggregate (RCA). Recycled concrete aggregate is appropriate for several applications, including the following:

- Substitute for virgin aggregate in new concrete or asphalt pavements. It is especially useful in mixtures for the bottom lift of two-lift concrete pavement construction projects.
- Unbound pavement bases.
- Dense-graded bases.
- Drainable bases (with design accommodations for the generally high pH values of effluent from such bases).
- Riprap.
- Fill material or backfill.
- Pipe bedding.

RCA used as fill material or riprap can play a role in reducing atmospheric CO_2 by sequestering it. Where conditions are favorable for accelerated carbon sequestration, RCA has the potential to recover up to 50 percent of the CO_2 released during manufacture of the cement used in the original pavement.

The use of RCA provides societal benefits by reducing the need for landfills and quarries. Local recycling (i.e., using RCA in the concrete's original location) is especially advantageous because it results in a zero waste stream and reduces the carbon footprint, embodied energy, and emissions related to extracting and hauling virgin aggregate.

Assessing Concrete Pavement Sustainability

Good engineering has always entailed working with limited resources to achieve an objective. The focus on sustainability has simply increased the scope of the objective, along with the period of time over which the solution is evaluated. Now environmental and social factors must be considered equally with economic factors, and all impacts are considered from inception (e.g., mining of raw materials) to end of life, or recycling—a "cradle to cradle" analysis (McDonough and Braungart 2002).

A comprehensive sustainability analysis system will ultimately be required to fully realize the opportunities in and measure progress toward sustainable concrete pavements. At this juncture, however, the goal is simply to balance competing and often contradictory interests to effect incremental change. Several existing tools can help.

Economic analysis

Quite often, pavement designs with the lowest initial (design, material, and construction) costs will require higher renewal costs during the pavement's life, resulting in a greater life-cycle cost. Conversely, pavements built to last often have a greater first cost but a lower life-cycle cost. A life-cycle cost analysis (LCCA) is a useful economic decision support tool to select pavement type and materials. Every state highway agency is required to do some type of LCCA when using federal funds to support large projects. Software available from the FHWA (RealCost 2011) provides economic analysis of agency and user costs during a pavement's service life.

Environmental assessment

One way to assess environmental (and to some extent, societal) impacts of a product or process is to use life-cycle assessment (LCA). An LCA determines environmental impacts in terms of energy or mass use, including waste and emissions.

An LCA involves manipulation of large quantities of data. A model such as SimaPro (Pré 2011) provides data for common materials and options for selecting LCA impacts. However, several organizations have proposed alternate approaches. The Environmental Protection Agency's standard LCA procedures, for example, include the conduct of a life-cycle inventory (LCI) and a life-cycle impact analysis (LCIA).

Rating systems

Several rating systems are emerging that attempt to rate sustainable pavement practices. These systems often use elements of LCCA and LCA, integrated with other environmental and equity impacts, to assign points to alternative pavement solutions. GreenLITES (Leadership in Transportation and Environmental Sustainability) and Greenroads™, two of the most widely known rating systems, were developed by the New York State DOT (NYSDOT 2010). Others include the FHWA's INVEST (Infrastructure Voluntary Evaluation Sustainability Tool) (www.sustainablehighways.org/) and the Institute of Sustainable Infrastructure's Envision™ rating system (www.sustainableinfrastructure.org/). Both of these are based on the Greenroads™ system.

References

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McDonough, W., and M. Braungart. 2002. *Cradle to Cradle: Remaking the Way We Make Things*. New York, NY: North Point Press.

New York State Department of Transportation (NYSDOT). 2010. *GreenLITES Project Design Certification Program*.

PRé Consultants. 2011. *SimaPro 6*. Amersfoot, the Netherlands.

RealCost, www.fhwa.dot.gov/infrastructure/asstmgmt/lccasoft.cfm. Accessed April 2012.

Other Resources

For more information, see the following resources on the National CP Tech Center's website (www.cptechcenter.org):

- *Guide to Cement-Based Integrated Pavement Solutions*
- CP Road Map "Moving Advancements into Practice" (MAP) Briefs
- *Integrated Materials and Construction Practices for Concrete Pavement: A State-of-the-Practice Manual*
- *Testing Guide for Implementing Concrete Paving Quality Control Procedures*
- *Guide for Roller-Compacted Concrete Pavements*
- *Concrete Pavement Specifications for Reducing Tire-Pavement Noise*
- *Guide to Concrete Overlays (2nd edition)*
- *Guide for Partial-Depth Repair of Concrete Pavements*
- *Concrete Pavement Preservation Workshop Reference Manual*
- *Guide to Dowel Load Transfer Systems for Jointed Concrete Roadway Pavements*
- Resources on Two-Lift Concrete Paving