Seven Principles for Sustainable Concrete Pavements

In many ways, it comes down to practicing good engineering

by Thomas Van Dam and Peter Taylor

Sustainability is simply good engineering: optimizing resources, balancing competing interests, and making incremental improvements as knowledge improves.

So it's no surprise that the sustainability movement is making the concrete pavement industry more innovative and competitive. For evidence, consider the ongoing development of in-place recycling of existing concrete pavement, two-lift construction, safe and quiet surfaces, pervious concrete, optimized grading to reduce cementitious material content, and low carbon footprint mixtures with high supplementary cementitious material (SCM) contents.

Seven Principles of Sustainability

We've observed that sustainability efforts can be enhanced by following simple principles—each applied in terms of its interdependency with, and/or potential competition with, the other principles.

Principle 1: Get Smart

This is an exhortation to educate yourself about making concrete pavements an integral part of sustainable infrastructure. Education should not be restricted to formal study, but should be integrated with day-to-day operations.

Getting smart includes embracing the concept of the life cycle. Design, materials processing, construction, operations, preservation/rehabilitation, and reconstruction/recycling all affect pavement sustainability. These processes must be clearly understood and appropriately applied.

Specific actions include:

- Review relevant information—the references at the end of this article are a good place to start;

- Design what you need—overdesign is wasteful, and underdesign results in unacceptable performance;

- Design holistically—include pavement support conditions, material availability and properties, environmental conditions, traffic, and community considerations (refer to Principle 2). Important design elements include not only slab thickness, but also materials selection, joint spacing, load transfer, drainage, supporting layers, and surface texture;

- Enhance educational programs—education for new and practicing professionals must include current sustainable materials and practices; and

- Use the right tools—if there is a need for new materials and practices, support their development.

The National Concrete Pavement Technology Center (CP Tech Center) is developing a Manual of Practice for sustainable concrete pavements. Partially funded by the Federal Highway Administration (FHWA), the manual is targeted for publication by the end of 2011. Chapter topics will include:

- Sustainability concepts;
- Design;
- Materials;
- Construction;
- The use phase;
- Renewal;
- End-of-life strategies;
- Assessment of sustainability; and
- Future developments.

For more information regarding the Sustainable Concrete Pavements: Manual of Practice, visit www.cptechcenter.org.
**Principle 2: Design to Serve the Community**

Practice context-sensitive design (CSD), focusing on the needs of the user, the adjacent communities, and the environment. For high-speed roadways, CSD will encourage the use of surface textures that provide safe yet quiet riding surfaces (Fig. 1). For low-speed neighborhood streets, however, CSD will encourage aesthetics, high reflectivity, surface drainage, and traffic calming. Here, a purposefully designed “rough” surface may be desired, encouraging slower traffic and creating a more livable community.

Implementation requires early and continuous involvement of everyone who is affected.

Pavements designed to serve the community reflect their location, melding physically and visually within the environment. So, although it can take time, CSD ultimately results in increased societal acceptance and project efficiency. More information can be found at www.contextsensitivesolutions.org.

**Principle 3: Choose What You Use**

Whether an existing pavement is concrete, hot-mix asphalt, or a combination of the two, the existing pavement and its supporting layers can be effectively used in the construction of new concrete pavement. This will not only reduce the amount of material extracted from quarries, but it will also reduce the environmental and monetary costs of transporting materials from off site. But recycling these materials requires an in-depth understanding of their engineering properties.

Even if a local aggregate is known to have poor wear resistance, be susceptible to freezing-and-thawing cycles, or be prone to alkali reactivity, it need not be rejected out of hand. The Recycled Materials Resource Center provides a good starting point for investigating various recycling options. For example, an aggregate with poor wear resistance can be used in two-lift paving, placing the aggregate below the wearing surface. An aggregate with low resistance to freezing and thawing can be used by limiting its size and blending it with a durable, large-sized coarse aggregate. An aggregate with a history of alkali reactivity can be used in a mixture with a sufficient SCM content to mitigate the reaction (this will also reduce the carbon footprint of the concrete).

**Principle 4: Less is More**

All things being equal, a design that uses less virgin material is generally more sustainable (refer to Principles 1 and 3). Also, as indicated in Principle 3, SCMs can boost the durability of a mixture and reduce the associated generation of CO₂.

In addition to using SCMs, the portland cement content of concrete can be reduced by lowering the total cementitious material content. Mixtures used for pavements have traditionally had a minimum cement content of 564 lb/yd³ (335 kg/m³) (the proverbial “six-sack mix”). However, optimized aggregate grading permits a reduction in cementitious material content to as little as 470 lb/yd³ (279 kg/m³). Such mixtures can be less prone to segregation, easily consolidated during slip forming, and generally less prone to shrinkage and other negative effects associated with high cement paste contents.

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*Fig: 1: Scans of the surface profiles of 100 x 200 mm (4 x 8 in.) concrete samples with tine-formed grooves. A relatively subtle change in surface profile lowered the noise level associated with wheel travel across the grooves from 111 to 103 dBA (adapted from Reference 5)*
Concrete pavement life can therefore be increased, benefiting the project over its life cycle (refer to Principle 7).

Principle 5: Minimize Negative Impact
Sustainable construction minimizes noise, provides a safe working environment, minimizes disruption to the public, produces less emissions and construction waste, reduces water use, and increases the efficiency of equipment and processes. The finished concrete pavement should provide a quiet, safe driving surface; require minimal maintenance; effectively address water run-off; improve the energy efficiency of vehicles; reduce the energy required for artificial lighting; and mitigate the heat-island effect.

Concrete pavements can be made quiet and safe through the use of drag-textured or longitudinally tined surfaces or through diamond grinding. Water use during construction can be dramatically reduced by reusing wash water. Pervious surfaces can minimize run-off. Concrete pavements, particularly those produced using slag cement or light-colored fly ash, can minimize the heat-island effect because they have greater reflectivity than other pavement types.

Principle 6: Take Care of What You Have
Just as vehicles that are well maintained retain their value and provide more miles of service, well-maintained pavements deteriorate more slowly and have longer service lives. Sustainable pavements require agencies to:
- Evaluate existing pavements;
- Stay informed about preservation and rehabilitation;
- Systematically maintain pavements in good condition; and
- Systematically preserve and rehabilitate pavements for improved durability and surface friction.
With minimal investment, these activities restore or enhance a pavement’s level of service and can extend its life significantly.
Typically, the window for preventive maintenance is about 10 to 15 years after construction. The most common treatments include making partial- and full-depth repairs, dowel bar retrofitting, joint rescaling and crack sealing, and diamond grinding.
Diamond grinding restores ride quality after repairs are completed. It improves skid resistance and significantly reduces noise, and it can be applied two or three times over the life of a pavement. The technique was first used on a section of I-10 in California in 1965; the same section was subsequently ground in 1983 and again in 1997. That section of I-10 is still in service today, carrying 2.25 million equivalent single-axle loads (ESALs).
One rehabilitation strategy is the use of concrete overlays (Fig. 2). Unbonded overlays in particular are high-performing rehabilitation strategies for concrete, asphalt, and composite pavements. By taking advantage of the existing pavement’s structural capacity, an overlay requires a minimum of new material to restore or even enhance pavement performance.
Without appropriate and timely maintenance, a pavement will continue to deteriorate. Once it has deteriorated to the point that only 40% of its life remains, the rate of deterioration accelerates. Then, pavement condition can deteriorate as much as 60% in only 12% of its design life.
When a concrete pavement reaches the end of its service life, it can be recycled into the base of a new pavement or as aggregate for new concrete. Highway agencies today have access to information about a variety of effective strategies to preserve existing pavements and enhance their capacity for less than the cost of reconstruction.

Principle 7: Innovate
Sustainability requires agencies and the industry to develop new ways of thinking and doing. We can no longer base decisions on economics alone, especially first costs. We must also consider environmental and social effects over the pavement’s life cycle (Fig. 3).
Life-cycle-based approaches encourage innovations such as overlays, two-lift construction, quiet texturing, internal curing, and precast pavement elements. The key to implementation is forming partnerships among funding agencies, designers, materials suppliers, contractors, and community representatives. Essential to such partnerships is shared risk. Innovation is more challenging than doing what is familiar. If unexpected results occur, it’s important to determine what went wrong and learn from the experience.

Fig. 2: Concrete overlays can restore or enhance pavement performance
Where Do We Go from Here?

Concrete pavement stakeholders already have practical tools for pavement sustainability. Progress is being made to develop life-cycle systems to analyze economic, environmental, and social factors, and sustainable pavement rating systems.

Research needs include:

- Materials, processes, and practices that reduce waste, energy consumption, water usage, pollutants, and social disruption;
- Strategies for preservation, rehabilitation, and recycling of concrete pavements;
- Refinement of life-cycle cost analyses for concrete pavements;
- Acquisition, preservation, and distribution of data as part of an environmental life-cycle inventory (LCI) of the individual environmental flows to and from a concrete pavement;
- Strategy selection criteria for economic, environmental, and social considerations; and
- Methods to enhance coordination and collaboration among researchers, designers, and contractors.

References


Selected for reader interest by the editors.