Sustainable Concrete Pavements

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Chapter 1
INTRODUCTION

It is becoming increasingly apparent that a host of human activities and development practices are negatively affecting the economic, environmental, and social well-being of the planet, putting future generations of humanity, as well as of other species, at risk. Confronted with this reality, stakeholders in the pavement industry are being challenged to adopt practices that maintain economic vitality while balancing environmental and societal needs.

At the same time, stakeholders are facing other challenges: Pavements are aging and deteriorating; one-third of the road system, about 1.3 million miles, is in poor condition or worse, receiving a grade of D- in the American Society of Civil Engineers report card (ASCE 2009A). Traffic volumes and vehicle loads continue to increase, putting more demands on the already stressed pavement system and, in major metropolitan areas, resulting in serious congestion problems. Roadway agency budgets continue to fall short of needed funds, with an estimated $115.7 billion annual shortfall from funding required to substantially improve pavement conditions. These challenges exist not only in a time of economic uncertainty but also within the developing realization that the environmental and social impacts of these pavements systems are great.

The people responsible for the management, design, construction, maintenance, and rehabilitation of the deteriorating network of pavements are overwhelmed, recognizing that the current approach to solving problems inherent in the nation's pavement infrastructure is not sustainable. What is needed is a new approach, the implementation of truly sustainable pavement solutions that result in reduced economic cost over the life cycle, lessened environmental impact, and enhanced societal benefit, while maintaining the system in a high level of service for perpetuity. Recognizing this, many public agencies are adopting more "sustainable" practices and are beginning to rate, incentivize, and even award projects based on their demonstrated ability to enhance sustainability.

Yet, the basic questions remain: What is sustainability? What attributes of concrete pavements can make them a sustainable choice? Why is an emphasis on sustainability important for the concrete pavement industry?

1. What is Sustainability?

A basic definition of sustainability is the capacity to maintain a process or state of being into perpetuity, without exhausting the resources upon which it depends nor degrading the environment in which it operates. In the context of human activity, sustainability has been described as activity or development "that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED 1987).

Typically, three general categories (or pillars) of sustainability are recognized: economic, environmental, and social. When activities are sustainable, no pillar is ignored; instead, a workable balance among the three often-competing interests must be found. Together, the three pillars form what is commonly called the "triple bottom line" (Elkington 1994). This concept can be expressed graphically as shown in Figure 1.1, which illustrates that sustainable solutions are those that incorporate all elements of the triple bottom line.

Although this is a common definition of sustainability, it is somewhat dissatisfying as it doesn't define what is and is not important and it doesn't provide clear direction as to what must be done differently in the future to improve upon the present. This manual provides such definitions and directions, as they are currently understood, regarding concrete pavements.

Figure 1.1 Graphical representation of sustainability's "triple-bottom line" of economic, environmental, and societal considerations

Balancing economic, environmental, and societal factors for a pavement project requires identifying applicable factors in each category, collecting data for the factors to be evaluated, applying tools to quantify the impact of each factor, and assessing the combined impact of the factors in relationship to one another. Complicating the process is the fact that factors must be identified and measured/estimated during all stages of a pavement's life—design, materials selection, construction, operation, preservation/rehabilitation, and reconstruction/recycling. In other words, assessment of the sustainability of a project will require the use of a robust, sophisticated analysis.

It is recognized that a complete assessment of sustainability is beyond the current state of the practice and, in truth, may be impossible. Still, the application of available tools will assist in making incremental progress in achieving more sustainable concrete pavements.

2. Concrete Pavements and Sustainability

Concrete pavements suffer from a perception that they contribute a considerable amount of carbon dioxide (CO_2) to the atmosphere due to the use of portland cement that binds the aggregates together. Although portland cement manufacturing is an energy intensive process and does result in significant CO_2 emissions, partly due to the pyroprocessing required and partly due to the calcination of limestone (discussed in Chapter 4), advances in cement production have greatly decreased these impacts relative to even a few years ago. In addition, and just as important, modern concrete for pavements uses less portland cement per cubic yard relative to past practices, and thus concrete pavements have a lower carbon footprint than at any time in history. Further, future innovations will ensure additional improvements in reducing the carbon footprint and energy use over the next decade. When all aspects of sustainability are considered, especially when accounting for the pavement's life cycle,

properly designed and constructed concrete pavements are clearly part of a sustainable transportation system.

Following are a few general attributes of concrete pavements that can make them a sustainable choice:

- Long life: Achieving the desired design life with minimal future preservation activities results in reduced user delays and associated economic and environmental impacts over the life cycle.
- Smooth, quiet, and safe over the life cycle: Motorists experience a comfortable ride; drag is minimized for enhanced vehicle efficiency; pavement surface visibility and skid resistance are maximized through minimal preservation activities.
- Increased use of industrial residuals and reduced use of non-renewable resources.
- Fully recyclable.
- Cost effective: Demonstrated over the life cycle, concrete pavements preserve their equity long into the future.
- Minimal impact to the surrounding environment: In-place concrete pavements have no adverse effect on, and are not adversely affected by, atmospheric conditions, the natural environment, etc.
- Minimal traffic disruption during construction and preservation activities.
- Community friendly: Aesthetically pleasing, appropriately textured, light colored surfaces reduce ambient noise, emissions, surface run-off, urban heat, and artificial lighting needs, resulting in a positive local and global impact.

Strategies for design, material selection, construction, operation, maintenance/rehabilitation, and reconstruction/recycling are already being implemented that create concrete pavements with these attributes. Some of these strategies have been part of standard practice for over 100 years, resulting in incredible longevity and cost effectiveness, the hallmarks of concrete pavement. Others strategies, although demonstrated, are in the initial phase of implementation. This manual of practice focuses on concrete pavement strategies that can be readily implemented to enhance sustainability.

3. Why Should the Concrete Pavement Industry Care about Sustainability?

Before considering strategies to increase sustainability, it is first necessary to take a step back to consider why this is important to the concrete pavement industry.

First, sustainability is not really new; it simply raises the bar for good engineering. Good engineering has always entailed working with limited resources to achieve an objective. What has changed is the scope of the problem, along with the period of time over which a project is evaluated. Whereas in the past economic factors were paramount, now environmental and social factors must be considered equally with economic factors. Whereas in the past initial costs and other initial impacts were often paramount, now the span of time in the analysis is increased to the entire life cycle of a project, and all impacts (both positive and negative) are considered from the point of inception (e.g., mining of raw materials) to end of life (e.g., recycling). This type of analysis is often referred to as a "cradle to cradle" analysis (McDonough and Braungart 2002).

Such an all-encompassing scope over such a long analysis period requires a systems approach to fully realize the opportunities to implement sustainable design. At this juncture, sustainable design is not about achieving perfection but about balancing competing and often contradictory interests to bring about incremental change. Although most civil engineers find the idea of sustainability as the new standard for good engineering to be a challenging prospect, many find it engaging as well. As sustainable design continues to evolve, so will the role played by the concrete pavement industry.

Second, sustainability is increasingly being demanded by a diverse number of stakeholders. One major group of stakeholders is the public. ASCE's Board of Direction recently approved the following statement (ASCE 2009B):

> The public's growing awareness that it is possible to achieve a sustainable built environment, while addressing such challenges as natural and man-made disasters, adaptation to climate change, and global water supply, is reinforcing the civil engineer's changing role from designer/constructor to policy leader and life-cycle planner, designer, constructor, operator, and maintainer (sustainer).

This statement recognizes that one of the driving forces for the changing role of the civil engineer as a "sustainer" is the "public's growing awareness" that a more sustainable built environment is achievable. Civil engineers are being required to examine alternative solutions that a few years ago might not have been considered. This idea is clearly annunciated in the integrated global aspirational vision statement adopted at *The Summit on the Future of Civil Engineering* held in 2006, which stated that civil engineers are "entrusted by society to create a sustainable world and enhance the global quality of life" (ASCE 2007). This is a large aspiration, reflecting the responsibility entrusted by the public to those charged with designing, constructing, operating, preserving, rehabilitating, and recycling infrastructure including concrete pavements.

Another group of stakeholders, more directly relevant to the concrete pavement industry, includes local, state, and federal pavement owner agencies. As mentioned previously, various agencies have begun to require that sustainability metrics be measured on paving projects and may use such metrics in the selection process for future transportation projects.

Third, today's increasing focus on sustainable infrastructure offers an opportunity for the concrete pavement industry to communicate the positive contributions inherent in concrete pavement. Because of its versatility, economy, local availability, and longevity, concrete is the most commonly used building material on the planet; it is not hyperbole to say that modern civilization is literally built on concrete. Due to the sheer volume of concrete in use and its many sustainable attributes, it has a relatively large environmental footprint as well as immense positive impacts on sustainability. The concepts related to sustainability provide a positive language through which industry can communicate the good being done through the use of concrete pavement rather than solely disputing unjustifiable perceptions of harm.

Fourth, adopting sustainability principles and practices will make the concrete pavement industry more attractive to a younger workforce. Peter Senge et al. (2009), in their book, *The Necessary Revolution: How Individuals and Organizations are Working Together to Create a Sustainable World*, state that employees are making career choices based on an organization's commitment to sustainability. Yet even ASCE, in the last sentence of the Board of Direction's statement cited earlier (ASCE 2009B), has recognized that civil engineers are often perceived as part of the problem, not the solution: "Civil engineers are not perceived to be significant contributors to a sustainable world." With this backdrop it is clear that, to attract the young talent needed for the future, industry must change such negative perceptions through the advancement of sustainable concrete infrastructure, including pavements.

And, finally, enhancing sustainability will make the concrete pavement industry more innovative and more competitive. This can be observed already through such diverse innovations as in-place recycling of existing concrete pavement, two-lift construction, safe and quiet surface characteristics, pervious concrete, optimized aggregate gradations that reduce cementitious material content, and the trend toward concrete with higher supplementary cementitious material (SCM), to name a few. Each of these examples clearly demonstrates positive economic, environmental, and social impacts. Emerging concrete technologies that are poised to bring even more dramatic positive changes include photocatalytic cements to treat air pollution, carbon sequestering cements and aggregates, further increases in SCM content, embedded sensing technologies for construction and infrastructure health monitoring, and advanced construction processes that minimize energy use and emissions.

The challenge to the industry is to step out of the box and, instead of focusing on simply meeting existing specifications, "re-imagine" what a concrete pavement can be and work with the various stakeholders to further increase the economic, environmental, and social benefits inherent in concrete pavements.

4. Organization of This Manual

Fortunately, many best practices already exist for constructing new concrete pavements as well as preserving or rehabilitating existing ones in a manner that significantly contributes to the sustainability of the nation's highway system. Decision makers, engineers, material suppliers, and contractors need practical guidance on adopting these solutions and considering their relative benefits in the context of limited budgets, increased

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