Sustainability and Concrete Pavements for Real Engineers

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Concrete Sustainability Conference
April 13, 2010
What’s The Deal With Sustainability?

- I have to confess: I am getting sick of this word!
- Is it a code word for “environmentalism”?
- Is its purpose to simply sell products?
- Is it only being used to advance “sustainability science” giving academics another trough to eat out of?
- Am I just getting old and crabby?
Let’s Keep It Real and Keep It Simple

Sustainability balances:
– Economic considerations
– Environmental considerations
– Social considerations

Over the life cycle!
The Goal: Enhanced Sustainability

Pulling Considering all unevenly takes the system out of balance

Environmental

Social
Sustainable Design

- Sustainable design must consider life-cycle economic, environmental and societal factors
  - Economic factors addressed through life-cycle cost analysis (LCCA)
- It is simply good engineering
  - It entails working with limited resources to achieve design objectives
  - It is not about perfection, but instead about balancing competing, and often contradictory, interests
The Life Cycle: A Key Concept

The 'life cycle' includes all phases of a pavement’s existence including raw material production and transportation, construction, operations, and renewal (preservation, restoration, rehabilitation, and disposal/recycling)

– The sum of these steps - or phases - is the life cycle of the pavement
Cradle-to-Cradle Life Cycle

- Design
- Materials Processing
- Construction
- Operations
- Renewal
- Preservation and Rehabilitation
- Reconstruction and Recycling
Today, Sustainability...

- Is being demanded by a diverse number of agencies, organizations and the public
- Allows the concrete industry to communicate the good that is being done
- Makes concrete more competitive
- Drives innovation
In Addition…

- Sustainability metrics are being developed and will be required on Federally funded projects in the near future
  - Already adopted by some states and local agencies

- A lot of excellent work has been done to characterize sustainable attributes of pavements and more is in the pipeline
Is Asphalt or Concrete a More Sustainable Paving Material?

Yes
- It depends on the context and how sustainability is defined

The models currently lack the accuracy to make a definitive choice
- All studies have caveats and limitations

The situation is dynamic

This is the wrong question!
The Right Question Is “How Can We Make Concrete Pavements Better?”

- Design for the long-run
- Choose the right materials
- Consider operations
- Trust but verify

Design for the Long-Run

- Educate yourself, your colleagues, and all stakeholders
- Use a holistic approach to design – it is not just thickness or long-life
- Design for what you need
  - Context sensitive design (CSD)
- Evaluate innovative features and use those that work
Multiple Design Attributes

- Improved Fuel Economy
- Lower Energy Footprint
- Aesthetically Pleasing
- Light Colored and Cool
- Less Fuel Consumed, Less Water Used, and Less Waste Generated During Construction
- Treat Air Pollution
- Industrial By-Product Use
- Renewal and Recycling
- Improved Stormwater Quality
- Structural Capacity
- Quiet Surface Textures
- Two-Lift Construction

Adapted from Wathne, ACPA
Context Sensitive Design

- Are all designs equally desirable for every situation?
  - Urban versus rural?
  - High-speed versus slow-speed?
  - Arterial versus local?

- Understand the versatility of the material and take advantage of it
  - Thickness and joint spacing are a small part of design
Specific Real-World Examples

- Two-lift construction using materials suited to each layer
  - Example: recycled aggregate and high volume fly ash in bottom lift

- Use aesthetics for urban environments

- Emerging designs may represent “game changing” technologies
  - Ultra-thin overlays
  - Precast/paver systems
  - New Chilean design
Choose the Right Materials

- In 2008, domestic cement production was responsible for approximately 1.5% of U.S. total CO₂.
- Portland cement is responsible for approximately 90% to 95% of the CO₂ and 85% of the energy embodied in concrete.
- Without question, the “carbon footprint” of infrastructure will become more important.
CO$_2$ Emissions and Cement

The graph shows the pounds of CO$_2$/yd$^3$ for different percentages of replacement with SCM (secondary cementitious materials) and cementitious content (lbs/yd$^3$). The data indicates a decrease in CO$_2$ emissions as the percent replacement with SCM increases, suggesting engineering solutions to improve pavement performance.
CO$_2$ Emissions and Cement

## Concrete Mixtures for the I-35W Bridge (CI, February 2009)

<table>
<thead>
<tr>
<th>Component</th>
<th>Specified Strength (psi)</th>
<th>Cementitious Materials</th>
<th>CO₂ (lb/yd³)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Total  (lb/yd³)</td>
<td>Portland Cement (%)</td>
</tr>
<tr>
<td>Superstructure</td>
<td>6500</td>
<td>700</td>
<td>71</td>
</tr>
<tr>
<td>Piers</td>
<td>4000</td>
<td>575</td>
<td>15</td>
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<tr>
<td>Footings</td>
<td>5250</td>
<td>&lt; 600</td>
<td>40</td>
</tr>
<tr>
<td>Drilled Shafts</td>
<td>5000</td>
<td>&lt; 600</td>
<td>40</td>
</tr>
</tbody>
</table>
Specific Real-World Examples

- Reduce cementitious content in paving mixtures (564 lbs/yd³ to 470 lbs/yd³)
- Increased use of SCMs
  - Fly ash, slag cement, natural pozzolans
- Use blended (ASTM C595) or performance specified (ASTM C1157) cements
- Always consider in-place recycling
What About Operations?

- Approximately 85% of the energy and emissions associated with pavements is incurred after the construction phase.
- Social impacts are sizable.
- Need to consider operational phase:
  - Traffic using the facility
  - Interaction of the pavement with the surrounding environment
Fuel Efficiency

- Pavement roughness impacts vehicle operating costs, especially fuel efficiency
  - Keep pavements smooth
- Small, but significant, improvement in fuel efficiency when vehicles are operating on a rigid concrete pavement
  - Still awaiting publication of some key reports
- Over a 30 to 50 year design life, this can be huge
Surface Reflectivity

- Concrete surfaces are highly reflective
  - Can be made more so with lighter cement or coatings
- High reflectivity helps mitigate the urban heat island (UHI) effect
  - Reduces energy use and smog
- Highly reflective pavement surfaces also require less artificial light at night
  - Less energy and improved safety
Surface Albedo and Urban Heat
Pervious Surfaces

Concrete pavement can be made pervious
- Significant economic, environmental, and social benefits
- Part of a livable community

Integrate with conventional mainline paving

Consider photocatalytic cement
Specific Real-World Examples

- Chicago is using concrete pavers made with TiO$_2$ surface to address UHI effect
  - Also microsurfacing asphalt pavement
- Significant increase in the use of pervious concrete
  - Local streets, alleyways, parking lanes, and parking lots
- Consider improved fuel efficiency?
Trust But Verify

- “Greenwashing” is rampant
- An unbiased, scientifically-based “toolkit” is needed to assess the sustainability of all pavements
  - A life cycle assessment (LCA) framework for pavements (in compliance with ISO14040) is being worked on by a number of groups
  - Assessment of social impacts is challenging
- Rating systems are available (Greenroads)
Life Cycle Assessment

- An LCA compares environmental impacts assignable to producing goods
  - Scientifically-based
- It accounts for the effects of “cascading technologies”
- Conducting an LCA infers that a fair, holistic assessment is done over all phases of a product’s existence
  - Establishing a framework is very important
System Input-Output Concept

- Raw materials (kg)
- Feedstock (kg)
- Energy (MJ, kWh)
- Products (kg)
- Co-products (kg, MJ)
- Waste (kg)
- Emissions to water and soil (kg)
- Emissions to air (kg)
Specific Real-World Examples

- Rigorously employ LCCA
- Elements of Greenroads are ready to use
  - Coordinate with developers
- Thumbnail environmental assessment using published data
  - PCA Report
- Process LCA can be conducted for large projects
In Closing: Opportunities Exist

- Sustainability is here to stay, being driven by multiple economic, environmental, and social factors
  - It has always existed, but often ignored
- Profound change is impacting our industry
  - The versatility of concrete will ensure it remains a material of choice
Exploit Win-Win-Win Scenarios

- In-place recycling
- Increased use of SCMs, blended cements, and performance specified cements
- Optimized mix designs
- Two-lift construction
- Design and construct livable communities featuring concrete pavement
  - Light in color, aesthetic, pervious, innovative
Track 13 Products

- A Briefing Document (delivered 08/09)
- A “Best Practices” training manual and implementation package for concrete pavement sustainability (initiated 1/10)
- A conference on sustainability of concrete pavements that addresses economic, environmental, and societal impacts
  - International Conference on Sustainable Concrete Pavements: Practices, Challenges, and Directions, Sacramento, CA. Sept. 15-17, 2010
Questions?