Sustainable Pavement Design Using Geosynthetics

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Agenda

• Geosynthetics and their use in enhanced pavement design

• Sustainability and resilience in pavement design

• FHWA Sustainable Pavements Program

• The role of design in sustainability analysis

• Design example
Types of Geosynthetics

Geosynthetic Functions

1. Stabilization
2. Reinforcement
3. Separation
4. Filtration
5. Drainage
6. Containment
Function: Stabilization

Definition:
- Improves the mechanical behavior of unbound granular materials, by interlocking and confining their particles to minimize deformations caused by traffic loading.

Types of Geosynthetics:
- Multiaxial Geogrids
- Geocells
Function: Stabilization

Applications:
• Unpaved Haul/Access Roads
• Paved Roads
• Working Platforms
What are Geogrids?
# Mechanisms of Geogrids

<table>
<thead>
<tr>
<th></th>
<th>Mechanism</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Aggregate Confinement</td>
</tr>
<tr>
<td>2</td>
<td>Improved Bearing Capacity</td>
</tr>
<tr>
<td>3</td>
<td>Tension Membrane Effect</td>
</tr>
</tbody>
</table>

All mechanisms act together to **MAKE STONE PERFORM BETTER**

These mechanisms were identified and defined by ACE USACOE, Tngle & Webster (2003)
Mechanisms – Aggregate Confinement

Source: USACOE ETL 1110-1-189
Mechanisms – Aggregate Confinement
Mechanisms - Improved Bearing Capacity

Source: USACE ETL 1110-1-189
Small Scale Trafficking Tests

Unstabilized
3,000 passes

Biaxial Geogrid
10,000 passes

Triaxial Geogrid
10,000 passes
Common Geogrid Applications for Roadways

**Subgrade Stabilization**

- Bridge over soft soils
- Establish working surface
- Reduce fill thickness
- Reduce or eliminate undercut
- Replace mechanical mixing
- Replace chemical stabilization
- Provide uniform support condition
- Reduce maintenance

**Pavement Optimization**

- Stiffen aggregate base material
- Reduce aggregate/asphalt thickness
- Replace mechanical mixing
- Provide increased reliability
- Reduce maintenance
- Extend roadway life
Options for Addressing Weak Subgrades

- **Excavate and Replace** – remove the poor-quality soil and replace it with better material

- **Thicker Base or Sub-Base Layer** – Use more granular material on top of the poor subgrade

- **Augment the Subgrade Soil** – Use lime or other chemical treatments to improve the soil’s strength

- **Mechanical Stabilization** – Use geogrid to stabilize the subgrade
Subgrade Stabilization Design

- **Traffic**
  - Axle load: 20kip
  - Tire pressure: 100psi
  - Axle passes: 10,000

- **Comparison**
  - **Unstabilized**
    - 28 in
    - 1.2% CBR
    - $32.23/yard
    - 53% savings
  - **NX850**
    - Base + NX850
    - 1.2% CBR
    - $15.06/yard
    - 53% savings
  - **TX7**
    - Base + TX7
    - 1.2% CBR
    - $16.51/yard
    - 49% savings
  - **Biaxial Class 2**
    - Base + Biaxial Class 2
    - 1.2% CBR
    - $21.57/yard
    - 33% savings
Pavement Design Using AASHTO93

\[
\log_{10}(W_{18}) = Z_R S_o + 9.36 \log_{10}(SN + 1) - 0.20 + \frac{\log_{10}\left(\frac{\Delta PSI}{4.2 - 1.5}\right)}{0.40 + \frac{1094}{(SN + 1)^{5.19}}} + 2.32 \log_{10} M_R - 8.07
\]

\(W_{18}\) = Allowable ESALs
\(Z_R\) = Standard normal deviate
\(S_o\) = Standard deviation
\(SN\) = Structural number
\(\Delta PSI\) = Change in serviceability
\(M_R\) = Subgrade resilient modulus

- Converted to a layer depth using coefficients.
  - \(SN = a_1 D_1 + a_2 D_2 m_2 + a_3 D_3 m_3 + \ldots\)
  - \(a = \) ENHANCED (base) structural layer coefficient
  - \(D = \) layer thickness (inches)
  - \(m = \) layer drainage coefficient (typ. 1.0)
Pavement Optimization

Conventional Design

- 116,900 ESALs

Stabilized Option 1

- 1,041,300 ESALs

Stabilized Option 2

- 116,900 ESALs

Minimum Construction Cost

Stabilized Option 3

- 372,500 ESALs

Equivalent Cost
Sustainability and Resilience

- **Resilience or Resiliency**: the ability to anticipate, prepare for, and adapt to changing conditions and withstand, respond to, and recover rapidly from disruptions (FHWA)

- **Sustainability**: to create and maintain conditions, under which humans and nature can exist in productive harmony, that permit fulfilling the social, economic, and other requirements of present and future generations (NEPA)

Resilience supports sustainability in infrastructure in almost every case, both by minimizing required inputs and supporting broader goals for humans and nature.
What is an EPD?

An Environmental Product Declaration (EPD) is defined by ISO as a declaration that "quantifies environmental information on the life cycle of a product to enable comparisons between products fulfilling the same function".
Triple Bottom Line
Ensure that pavements are designed, constructed, preserved, and maintained to accommodate current and predicted traffic needs and consider economic, environmental, and social impacts and needs throughout the pavement's life cycle.
1. Achieve the engineering goals (performance).
2. Preserve and (ideally) restore surrounding ecosystems.
3. Use financial, human, and environmental resources wisely.
4. Meet basic human needs such as health, safety, equity, employment, comfort, and happiness.
Advance the knowledge and practice of designing, constructing, and maintaining more sustainable pavements through:

- Stakeholder engagement
- Education
- Development of guidance and tools
Quantification Methods

• Environmental Product Declarations (EPD)
  • LCA-based, transparent and verified report of environmental impacts of a product

• Life Cycle Assessment (LCA)
  • Method to quantify environmental impacts of products and processes over life cycle
LCA Benchmarking Tool

- Created with stakeholder input
- Use the identified background datasets
- Incorporate material EPDs

Available at: https://www.fhwa.dot.gov/pavement/lcatool/
## Inflation Reduction Act of 2022

<table>
<thead>
<tr>
<th>Section No.</th>
<th>Agency</th>
<th>Funding</th>
<th>Title</th>
<th>Expiration Date</th>
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<td>60112</td>
<td>EPA</td>
<td>$250M</td>
<td>Environmental Product Declaration Assistance</td>
<td>Sept. 30, 2031</td>
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<tr>
<td>60116</td>
<td>EPA</td>
<td>$100M</td>
<td>Low-Embodied Carbon Labeling for Construction Materials • Identify and label construction materials with lower embodied GHG • Production, Use, and Disposal</td>
<td>Sept. 30, 2026</td>
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<td>60503</td>
<td>GSA Federal Buildings Fund</td>
<td>$2.15B</td>
<td>Use of Low-Carbon Materials</td>
<td>Sept. 30, 2026</td>
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<tr>
<td>60506</td>
<td>DOT FHWA</td>
<td>$2B</td>
<td>Low-Carbon Transportation Materials Grants • Use of construction materials and products that have substantially lower embodied GHG Production, Use, and Disposal</td>
<td>Sept. 30, 2026</td>
</tr>
</tbody>
</table>
Carbon Reduction Program

• Purpose: To reduce transportation emissions through the development of State carbon reduction strategies and by funding projects designed to reduce transportation emissions (IIJA Pub. L. 117-58)

• Sustainable pavements and construction materials
  “Sustainable pavements technologies that reduce embodied carbon during the manufacture and/or construction of highway projects could be eligible for CRP if a lifecycle assessment (LCA) demonstrates substantial reductions in CO2 compared to the implementing Agency’s typical pavement-related practices. The LCA Pave Tool can be used to assess the CO2 impacts of pavement material and design decisions.”
Understanding the Role of Design

• Alternative design approaches often use products from different categories to achieve the desired result.

• If the design approach changes, a simple comparison of EPDs will yield flawed results.

• Operational and maintenance differences may also come into play with different designs.

• A valid analysis must cover both the proper **scope** and the proper **time frame**.
Scope of Consideration

- System
- Project
- Project Component
- Product
Assumptions and Limitations

- **Scope of Consideration** is critical to valid results
  - Material/design scope
  - Temporal scope

- Understand the data you have, and the **data you don’t have**

- For infrastructure projects, **construction is only the first part of the story**
  - **Cradle to Gate** tells a different story than **Cradle to Grave**
  - Maintenance is a major factor, but often unknown/unaccounted for
Example – Pavement Design

• 1 mile pavement, 30 feet wide
• AASHTO 1993 design
• Assumptions covering distances to project for asphalt, aggregate, geogrid
• Cradle to Gate + construction analysis

<table>
<thead>
<tr>
<th>AASHTO 1993 Design Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asphalt Layer Coefficient</td>
<td>0.42</td>
</tr>
<tr>
<td>Unbound Aggregate Layer Coefficient</td>
<td>0.14</td>
</tr>
<tr>
<td>Initial Serviceability</td>
<td>4.2</td>
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<tr>
<td>Terminal Serviceability</td>
<td>2.0</td>
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<tr>
<td>Aggregate Drainage Factor</td>
<td>1.0</td>
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<tr>
<td>Reliability</td>
<td>95%</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>0.49</td>
</tr>
</tbody>
</table>

Conventional Design
552,700 ESALs

MSL Used for Life Extension
4,055,500 ESALs

Design Optimized for Minimum Cost
625,000 ESALs
Example – Pavement Design

- **Scope of Consideration** – a design change must be considered as a whole
- Understand the data you have, and the **data you don’t have** – which inputs require assumptions, and what is their sensitivity?
- For infrastructure projects, **construction is only the first part of the story** – lifespan and maintenance requirements can exceed construction inputs
## Example – Pavement Design

<table>
<thead>
<tr>
<th>Pavement Section</th>
<th>Calculated Traffic Capacity (ESALs)</th>
<th>GWP Through Initial Construction (kgCO₂e)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional Design, 4 in / 15 in</td>
<td>552,700</td>
<td>228,000</td>
</tr>
<tr>
<td>MSL Design, 4 in / 15 in</td>
<td>4,055,500</td>
<td>235,000</td>
</tr>
<tr>
<td>MSL Design, 4 in / 8 in</td>
<td>625,000</td>
<td>197,000</td>
</tr>
</tbody>
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- **Conventional Design, 4 in / 15 in**: 552,700 ESALs, 228,000 kgCO₂e
- **MSL Design, 4 in / 15 in**: 4,055,500 ESALs, 235,000 kgCO₂e
- **MSL Design, 4 in / 8 in**: 625,000 ESALs, 197,000 kgCO₂e

*Images:
- Conventional Design
- MSL Used for Life Extension
- Design Optimized for Minimum Cost*
Summary and Key Points

• Mechanical aggregate stabilization using geogrid offers significant benefits for pavements:
  • Performance
  • Life cycle cost
  • Sustainability
  • Resilience

• Environmental Product Declarations (EPDs), when properly used in construction, provide information necessary to perform Life Cycle Analysis (LCA) for project sustainability

• Pavement sustainability and resilience are a primary focus at FHWA through the Sustainable Pavement Program and other funding programs in the BIL and IRA
Summary and Key Points

• **Design is a complicating factor**

• **Scope of Consideration** is critical to obtaining valid results
  • What’s included?
  • Over what timeframe?

• The ideal scope of consideration would be set where design changes do not affect results at the next level

• As engineers, we are responsible for **asking and answering the big questions**, and doing so in a rigorous, clear-eyed, and ethical manner

• Are we considering the proper scope when we consider sustainability?
Thank You

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