TIRE-DERIVED AGGREGATE
STRUCTURAL ANALYSES RESEARCH STUDY

PennDOT Pollution Prevention – Strategic Recycling Program
Recycling in Pennsylvania is governed by the Municipal Waste Planning, Recycling, and Waste Reduction Act (Act 101) of 1988, which was re-authorized as Act 175 in December 2002.

The Act 101 specifically directed PENNDOT to evaluate products and materials that may be recycled in transportation and civil engineering applications.

Since 1998, PennDOT and the Pennsylvania Department of Environmental Protection (PADEP) have operated under a Memorandum of Understanding (MOU) to promote and support recycled materials in state highway construction and maintenance projects.
The SRP was developed as a tool to systematically identify, evaluate, and implement recycling opportunities throughout Pennsylvania.

The ultimate objectives of the SRP is to realize economic savings and environmental enhancement to PENNDOT and the Commonwealth, continued development and improvement to pollution prevention, recycling, energy efficiency, and sound environmental management practices.
PENNDOT Strategic Recycling Program
Focus Areas of SRP

**Research:** To collect information on recycled materials (per literature reviews and laboratory, pilot, and field scale studies, as warranted.

**Specifications:** To develop, obtain, and/or disseminate user guidelines, provisional special provisions, and Publication 408 specifications at the Municipal, District, and Statewide levels.

**Projects:** To identify, implement, evaluate, and monitor projects that use recyclable materials.

**Outreach:** To communicate and disseminate the results and experiences of recyclable materials projects to PennDOT, Commonwealth agencies, and the public, through a variety of formats.

**Contracting:** To provide technical assistance to the Engineering Districts in developing and using purchase, service, and/or construction contract mechanisms to specify or provide for recyclable materials usage.
Recyclable materials/products that are currently used in PennDOT roadway transportation and maintenance projects include:

+ Recycled Asphalt Pavement (RAP)
+ Scrap Tires
+ Crushed Glass
+ Fly Ash
+ Blast Furnace Slag
+ Compost, Mulch, and Soil Amendments
+ Asphalt Shingles
+ Reclaimed Portland Cement Concrete (RPCC)
+ Crumb Rubber
+ Spent Foundry Sand
+ Plastics
+ Aluminum
Why another Tire-Derived Aggregate Research Project?

- Identify Potential New Projects
- Cost Advantage or Not?
- What Range of Projects are Best Fit for TDA use?
WHAT IS TDA?

TDA STANDS FOR TIRE-DERIVED AGGREGATE

WHERE DOES TDA COME FROM?

+ TDA is developed from the controlled shearing, to specific gradation and composition requirements, of scrap rubber tires from various sources.

+ Cut fragments are generally between ½ inch and 12 inches in size.
ADVANTAGES OF TDA

+ Lightweight
+ Good Internal Strength
+ Free-Draining
+ Cost-Effective
+ Environmentally Friendly
ENGINEERING AND CONSTRUCTION APPLICATIONS FOR TDA

+ Lightweight Fill:
  • Embankments
  • Slope Restoration/Landslide Remediation
  • **Structure Backfill**

+ Vibration Attenuation

+ Thermal Insulation

+ Drainage Layers
Instrumented Field Projects in U.S.

Evaluating Use of TDA as Lightweight Backfill for Retaining Walls and Bridge Abutments

- Full-scale retaining wall test facility at University of Maine, 1993-1994
- Bridge abutment for S.R. 196 over Androscoggin River (Merrymeeting Bridge) for Maine DOT, 1996
- Pair of bridge abutments for Limestone Run Bridge (Tartown Bridge) for Pennsylvania DOT, 2003-2004
TARRTOWN BRIDGE PROJECT

+ Located near Kittanning, PA
+ PennDOT/PADEP collaboration
+ First use of TDA for embankment fill and abutment backfill in a PennDOT project
+ Case Study prepared by Apex Companies, LLC for all aspects of tire shredding and bridge construction project elements
+ Favorable results for TDA as lightweight alternative to conventional soils
+ Reduction of lateral forces on abutments and wingwalls from structure backfill
Item 9203-0100 Select Borrow Excavation, Structure Backfill, Tire-Derived Aggregate

Use Guidelines for Item 9203-0100b Select Borrow Excavation, Structure Backfill, Tire-Derived Aggregate

Item 9703-0100 Production of Tire-Derived Aggregate for Embankments and Backfills
ENGINEERING DESIGN PARAMETERS – TDA VS. CONVENTIONAL BACKFILL

**TDA MATERIAL**

Dry Density: 50 pounds per cubic foot
Active Earth Pressure Coefficient: 0.3
Equivalent Fluid Pressure: 15 pounds per cubic foot

**AASHTO No. 57 COARSE AGGREGATE**

Dry Density: 120 pounds per cubic foot
Active Earth Pressure Coefficient: 0.29
Equivalent Fluid Pressure: 35 pounds per cubic foot
TDA EMBANKMENT/BACKFILL LAYERING REQUIREMENTS

Source: PennDOT Construction Specifications

[Diagram showing layering requirements for TDA embankment]
### TDA RESEARCH STUDY - DESIGN CASES

**TDA and Conventionally-Backfilled Structures Compared:**

<table>
<thead>
<tr>
<th>Structure Type</th>
<th>Bridge Abutment</th>
<th>Retaining Wall</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Structure Height</strong></td>
<td>15’</td>
<td>25’</td>
</tr>
<tr>
<td><strong>Foundation Type</strong></td>
<td>Spread on Soil</td>
<td>Piles on Rock</td>
</tr>
</tbody>
</table>

Total of 16 Design Cases - Designated 1C, 1T thru 8C, 8T (8 Design Categories - 1 thru 8)
DESIGN CASE MODELS - EXAMPLE
25’ ABUTMENT ON PILE FOUNDATION

CONVENTIONAL BACKFILL

HP 12 X 5.3 (Typ.) (A36) Steel Piles

BEDROCK

TDA BACKFILL

HP 12 X 5.3 (Typ.) (A36) Steel Piles

BEDROCK
MODELING DESIGN ASSUMPTIONS

+ All structure loadings, quantities, and costs are based on a 1-foot unit length of structure
+ Structure backfill configurations are in accordance with PennDOT Standard Drawing RC-12
+ All structures are assumed to be constructed in fill
+ Based on the assumed subsurface profile, pile lengths are considered to be 30’
Analysis and design for all abutment and retaining wall load cases was performed with PennDOT’s Computer Program, ABLRFD.
Input requirements of the ABLRFD program assume a uniform backfill material.

A set of composite soil backfill properties was calculated to approximate the lateral pressure behavior of the layered TDA/soil backfill configuration.

The values determined for these effective backfill parameters are dependent on the particular structure design height.
ABLRFD PROGRAM INPUT

LATERAL EARTH PRESSURE CALCULATIONS FOR LAYERED TDA/SOIL BACKFILL
COMPOSITE TDA/SOIL STRUCTURE BACKFILL PARAMETERS

15’ Structure Height
- Effective Internal Friction Angle: 35°
- Effective Dry Density: 80 pcf
- Effective Active Earth Pressure Coefficient: 0.27
- Earth Surcharge: 3.5 feet

25’ Structure Height
- Effective Internal Friction Angle: 37°
- Effective Dry Density: 80 pcf
- Effective Active Earth Pressure Coefficient: 0.25
- Earth Surcharge: 5 feet
FOUNDATION PARAMETERS

+ Spread Footings:
  - Foundation Material: Soil (1 layer)
  - Internal Friction Angle: 33°
  - Cohesion: 0 psf
  - Density: 120 pcf/130 pcf (dry/saturated)
  - Bearing Capacity Resistance Factor: 0.35
  - Sliding Resistance Factor: 0.8

+ Pile-Supported Footings
  - Pile Type: HP 12x53 (A36 steel)
  - Pile Axial Capacity: 140 kips/195 kips (service/strength limit)
  - Pile Batter: 1 horizontal: 4 vertical
LOADING PARAMETERS

+ For Bridge Abutments – typical values input:
  - superstructure dead load
  - bridge wearing surface dead load
  - vehicular live load
  - vehicular braking force
  - uniform temperature load
  - live load surcharge

+ For Retaining Walls – typical values input:
  - vehicular collision load
  - live load surcharge
DESIGN CASE RESULTS DRAWINGS - EXAMPLE
25’ ABUTMENT ON PILE FOUNDATION

CONVENTIONAL BACKFILL TDA BACKFILL
QUANTITY AND COST COMPARISONS

Quantities determined and tabulated for the following design items:

+ Concrete
+ Reinforcement Bars
+ Structural Backfill
+ Geotextile (for TDA design cases)
+ Piles (as applicable)
QUANTITY AND COST COMPARISONS

+ Concrete and reinforcement bars for footing and stem components of the structure quantified separately
+ Only primary/bending reinforcement was tabulated for reinforcement bar calculations
+ For TDA design cases, structure backfill quantities determined for both TDA material and soil embankment sub-layers
The following unit prices (in-place) were used for the design items:

- Concrete, Class A: $450/CY
- Steel Reinforcement Bars, Epoxy-coated, Grade 60: $1.50/LB
- Steel H-Piles, HP12x53, A36 Steel: $70/LF
- Steel Pile Tip Reinforcement, HP12x53: $125/EA
- AASHTO #57 Coarse Aggregate Select Borrow Material (conventional backfill): $60/CY
- TDA Select Borrow Material: $65/CY
- Soil Embankment: $20/CY
- Geotextile PennDOT Class 4, Type A: $3.75/SY
ITEM UNIT PRICES

+ Unit price for TDA material provided by Apex Companies, LLC
+ Unit prices for all other design items obtained from PennDOT Publication 287 – Construction Cost Catalog
Since structures are assumed to be constructed in a fill configuration, “net” unit price is used for backfill for cost comparison estimates.

Net unit price is calculated as price of select material in-place minus price of soil embankment in-place.

Resulting net structural backfill unit prices:

- **AASHTO #57 Coarse Aggregate Select Borrow Material:**
  
  \[ \text{Price of AASHTO } #57 \text{ Coarse Aggregate} - \text{Price of Soil Embankment} = \$40/\text{CY} \]

- **TDA Select Borrow Material:**
  
  \[ \text{Price of TDA Select Borrow Material} - \text{Price of Soil Embankment} = \$45/\text{CY} \]

- **Soil Embankment:**
  
  \[ \text{Price of Soil Embankment} - \text{Price of Soil Embankment} = \$0/\text{CY} \]
DESIGN COMPARISON TABLES

Item-by-Item breakdown and comparison of quantities/costs developed for each of the 8 design categories (1-foot unit length of structure basis)

Example of Design Comparison Table – TDA vs. Conventional Backfill (Table 1F - Design Category 6)

<table>
<thead>
<tr>
<th>Item</th>
<th>Unit Price</th>
<th>Units</th>
<th>Conventional Quantity</th>
<th>TDA Quantity</th>
<th>Conventional Cost</th>
<th>TDA Cost</th>
<th>TDA Savings Amount</th>
<th>TDA Savings %</th>
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<tbody>
<tr>
<td>Concrete</td>
<td>$450</td>
<td>CY</td>
<td>1.13</td>
<td>1.13</td>
<td>$508.50</td>
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<td>1.67</td>
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<td>$751.50</td>
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<td>2.80</td>
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<td>$1,260.00</td>
<td>$0.00</td>
<td>0.0</td>
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<tr>
<td>Reinforcement Bars</td>
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<td>LB</td>
<td>130.90</td>
<td>102.90</td>
<td>$1,965.35</td>
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<td></td>
<td>105.60</td>
<td>102.10</td>
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<td></td>
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<tr>
<td>Conventional</td>
<td>$340</td>
<td>CY</td>
<td>19.75</td>
<td>0</td>
<td>$790.00</td>
<td>$30.00</td>
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<tr>
<td>TDA</td>
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<td>CY</td>
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<td>10.54</td>
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<td>Soil Embankment</td>
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<td>$70.99</td>
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<td>Total</td>
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<td>19.82</td>
<td>$790.00</td>
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<tr>
<td>Abutment 15' Height</td>
<td>$30.00</td>
<td>0.0</td>
<td>$68.00</td>
<td>9.3</td>
<td>$30.00</td>
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<td>Abutment 25' Height</td>
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<tr>
<td>Total</td>
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<td>3.8</td>
<td>$0.00</td>
<td>0.0</td>
<td>$18.00</td>
<td>1.2</td>
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<th>Item</th>
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<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
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<tr>
<td>Concrete&lt;sup&gt;1&lt;/sup&gt;</td>
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<tr>
<td>Footing</td>
<td>$30.00</td>
<td>0.0</td>
<td>$68.00</td>
<td>9.3</td>
<td>$30.00</td>
<td>0.0</td>
<td>$18.00</td>
<td>3.4</td>
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<td>Stem</td>
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<td>$30.00</td>
<td>0.0</td>
<td>$0.00</td>
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<td>Total</td>
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<td>0.0</td>
<td>$54.00</td>
<td>3.8</td>
<td>$0.00</td>
<td>0.0</td>
<td>$18.00</td>
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<td>Reinforcement Bars&lt;sup&gt;2&lt;/sup&gt;</td>
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<tr>
<td>Footing</td>
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<td>$38.10</td>
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<td>$-32.70</td>
<td>-12.0</td>
<td>$0.00</td>
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<tr>
<td>Stem</td>
<td>$-30.45</td>
<td>-1.1</td>
<td>$34.05</td>
<td>2.6</td>
<td>$-30.30</td>
<td>-1.1</td>
<td>$33.90</td>
<td>3.0</td>
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<td>Total</td>
<td>$-60.90</td>
<td>-1.2</td>
<td>$121.15</td>
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<td>-6.0</td>
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<td>Steel H-Piles&lt;sup&gt;3&lt;/sup&gt;</td>
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<td>NA</td>
<td>NA</td>
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<td>NA</td>
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<td>Structural Backfill</td>
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<td>52.3</td>
<td>$297.65</td>
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<td>$116.05</td>
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<td>$323.60</td>
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<td>Geotextile&lt;sup&gt;4&lt;/sup&gt;</td>
<td>$-17.63</td>
<td>NA</td>
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<td>9.2</td>
<td>$280.66</td>
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</tr>
</tbody>
</table>
Quantity and Cost Results

+ Potential cost savings of approximately 9 to 15 percent for TDA backfill structures compared to conventional backfill structures.

+ For the 15’ height structures, TDA savings ranged from $90 to $165 per foot.

+ For the 25’ height structures, TDA savings ranged from $280 to $550 per foot.
Quantity and Cost Results (cont’d)

+ For spread footing structures, TDA savings are primarily due to backfill cost savings.

+ For pile-supported structures, TDA savings are due to foundation cost savings from reductions in steel piling and footing reinforcement along with backfill cost savings.

+ No significant reduction in concrete footing and stem quantities/costs for TDA structures.
Quantity and Cost Results (cont’d)

Structure Backfill

+ Overall quantities of structure backfill are similar for TDA and conventional structures.
+ Cost savings on backfill for TDA structures are significant, ranging from 40 to 52 percent.
+ Backfill cost savings are due to required layering of TDA material with significant volumes of lower cost common soil embankment.
+ TDA backfill savings range from $110 to $120 per foot for the shorter structures and $300 to $350 per foot for the taller structures.
TDA Modeling and Design Issues

- Hand calculations are necessary to simplify the layered TDA backfill model to a set of “composite” backfill properties compatible with the ABLRFD design program.

- A separate set of lateral earth pressure calculations are required for each different structure height.

- The design effect of the required soil sub-layering for TDA backfill is a moderation of the lightweight design properties of the TDA material.
TDA Modeling and Design Issues (cont’d)

+ The effect of structure height on TDA design is not a continuous, linear relationship, due to TDA/soil layering requirements.

+ The adjustments to the TDA lateral pressure design profile due to soil sub-layering are approximate; some degree of inaccuracy remains.
TDA study recommendations

TDA backfill offers potential cost savings as an alternative to conventional backfill for the following:

- abutments and retaining walls
- both deep-supported and shallow-founded
- across a fairly wide range of design heights
The following proposed TDA backfill structure design scenarios are offered, in ranking order, from highest to lowest anticipated potential for cost savings:

<table>
<thead>
<tr>
<th>Structure Design Height Range</th>
<th>Structure Foundation Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) 24’ to 30’</td>
<td>pile-supported</td>
</tr>
<tr>
<td>2) 24’ to 30’</td>
<td>spread footing</td>
</tr>
<tr>
<td>3) 12’ to 18’</td>
<td>pile-supported</td>
</tr>
<tr>
<td>4) 12’ to 18’</td>
<td>spread footing</td>
</tr>
</tbody>
</table>
With regard to pile-supported structures, longer piles would offer potentially higher cost savings.

The structure design height ranges identified above are approximate and intended for general comparisons only.

The height interval from 18’ to 24’ is not included because TDA/soil backfill layering requirements make the practicality and cost effectiveness of TDA use for that range of structure design heights less clear.
Soil-bearing material is assumed for the spread footings indicated in the ranking TDA design scenario listing; however, potential TDA savings may occur with rock bearing spread structures as well.

Although this study did not directly consider structures built in a cut ground situation, the general pattern and magnitude of TDA design savings resulting from this study can reasonably be expected to extend to such design configurations.
Study Limitations

+ The previous conclusions and proposed design scenarios are qualified by the following restriction:
  - TDA cannot be used in areas where maximum groundwater or floodwater levels can encroach to within two feet of the material, as specified in PennDOT’s Use Guidelines for TDA as structure backfill.

+ These recommendations are to be considered as approximate design guidelines and suggestions only.
Study Limitations (cont’d)

+ This study does not purport to have evaluated all design possibilities for abutments and retaining walls.

+ The scope of this study and its results are not intended to be extrapolated to, either in support or opposition of, the use of TDA in other, non-related, or non-evaluated design situations.
PROJECT CREDITS

+ Apex Companies, LLC – Prime Consultant, Jelena Vukov, PE, Project Manager

+ PennDOT Bureau of Maintenance, MTLD, SEMP Unit – Kenneth J. Thornton, PG, Chief

+ Project funded under Apex’s Strategic Recycling Program Management Contract No. 357R02 with PennDOT