GEOTECH TOOLS

43RD SOUTHEAST TRANSPORTATION GEOTECHNICAL ENGINEERING CONFERENCE

JAMES G. COLLIN, PH.D., P.E., D.GE
THE COLLIN GROUP

GEOTECH TOOLS

ENGINEERING TOOLS & TECHNOLOGY SELECTION GUIDANCE FOR GEOTECHNICAL, STRUCTURAL, AND PAVEMENT ENGINEERS

www.GeoTechTools.org

BACKGROUND

STRATEGIC HIGHWAY RESEARCH PROGRAM

Accelerating solutions for highway safety, renewal, reliability, and capacity

Project R02: Geotechnical Solutions for Transportation Infrastructure

Soil Improvement, Rapid Embankment Construction, and Stabilization of the Working Platform

What are Geotechnical Solutions? (Construction Options)

Geoconstruction and Ground Improvement (GI) Methods and Systems

- Methods to alter poor soil/ground conditions to meet project requirements
- Variety of GI methods, often categorized by densification, accelerate consolidation, reinforcement or chemical alteration, and stabilization

Project Team

Principal Investigators

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Donald Bruce, Geosystems, L.P.
Barry Christopher, Consultant
Jim Collin, The Collin Group, Ltd.
Gary Fick, Trinity Construction
George Filz, Virginia Tech
Jie Han, University of Kansas
Jim Mitchell, Virginia Tech
* Vern Schaefer, Iowa State University
Dennis Turner, The Transtec Group
Linbing Wang, Virginia Tech
David White, Iowa State University

SHRP 2 Project Manager

James W. Bryant, Ph.D. P.E.

** Project Managers*
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Jitendra Thakur, University of Kansas
Bin Tong, Iowa State University
Pavana Vennapusa, Iowa State University
Lee Vanzler, Virginia Tech
Chadd Yeatts, Virginia Tech

Advisory Board Members

State DOT Representatives

James Brennan	**Kansas DOT**
David Horhota	**Florida DOT**
Mark Morvant	**Louisiana TRC**
Hooshmand Nikoui	**Caltrans**
David Shiells	**Virginia DOT**
John Siekmeier	**Minnesota DOT**

Design/Build Contractor Representatives

Allen Cadden	**Schnabel Engineering**
Mike Cowell	**GeoConstructors, Inc.**
Seth Pearlman	**DGI-Menards, Inc.**
Steve Saye	**Kiewit Engineering**
Al Sehn	**Hayward Baker Inc.**

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STRATEGIC HIGHWAY RESEARCH PROGRAM

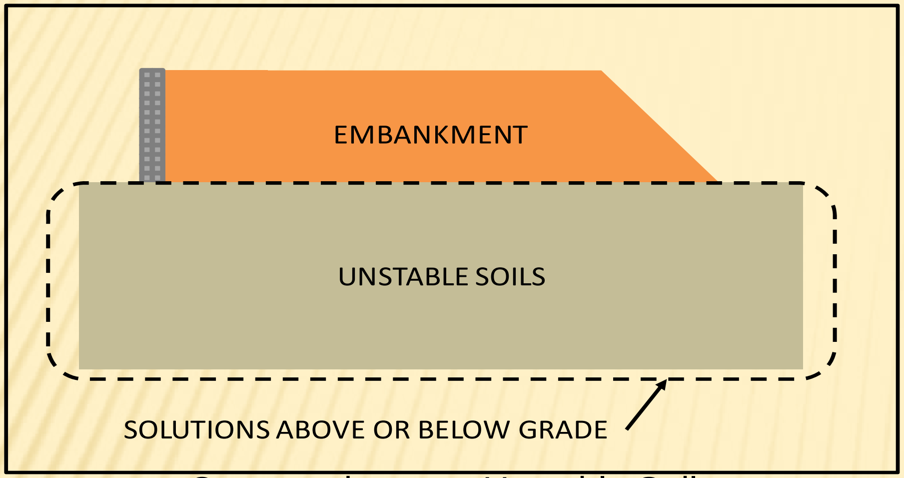
Accelerating solutions for highway safety, renewal, reliability, and capacity

R02 Project Elements

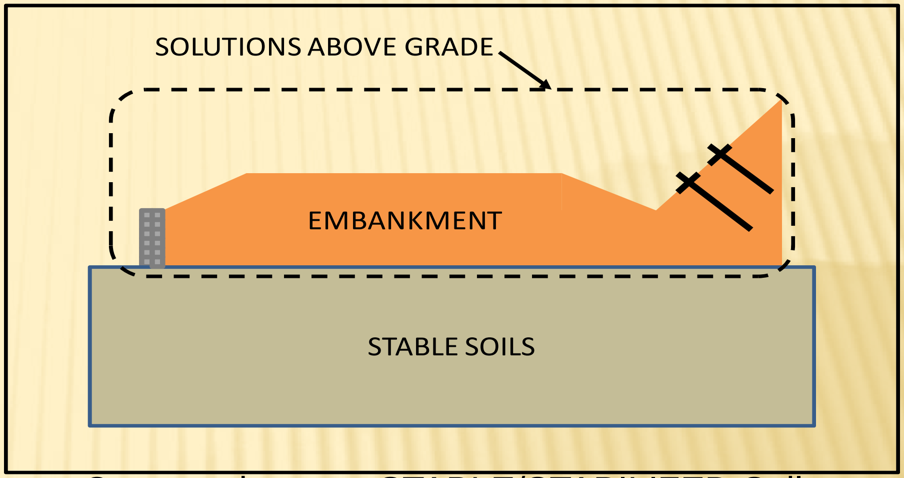
1 Construction of new embankments and roadways over areas of unstable soils

2 Widening and expansion of existing embankments and roadways

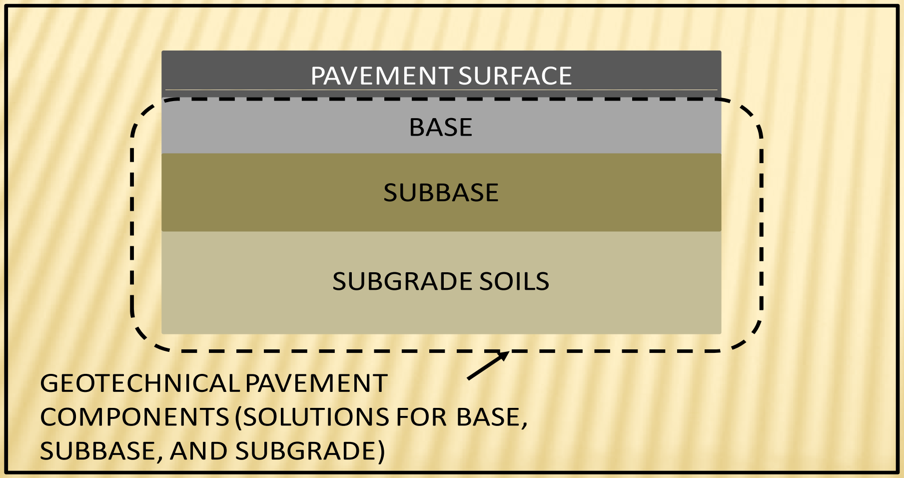
3 Improvement and stabilization of the support beneath the pavement structure



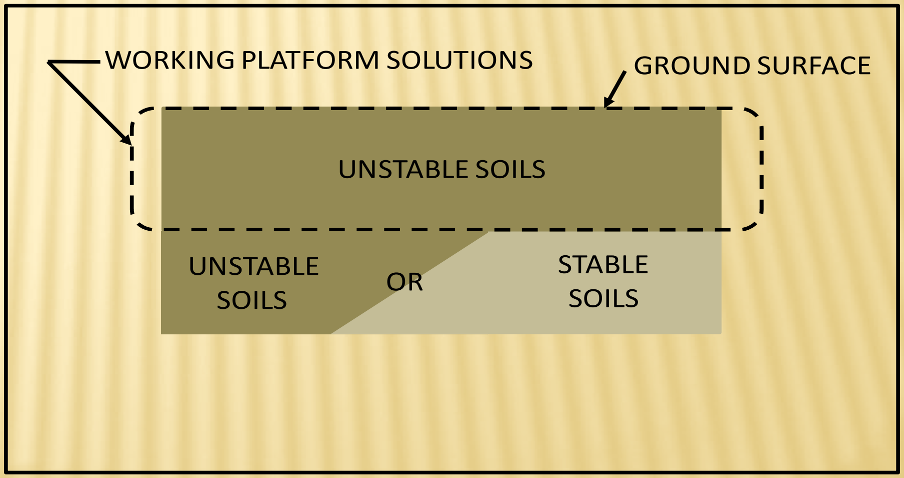
Construction over Unstable Soils



Construction over STABLE/STABILIZED Soils



Geotechnical Pavement Components (Base, Subbase, and Subgrade)



Working Platforms

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STRATEGIC HIGHWAY RESEARCH PROGRAM

Accelerating solutions for highway safety, renewal, reliability, and capacity

SHRP2 RENEWAL Objectives

1 **Rapid Renewal of transportation facilities**

2 **Minimal Disruption of traffic**

3 **Production of Long-Lived facilities**

46 TECHNOLOGIES ADDRESSED

- *Aggregate Columns*
- Beneficial Reuse of Waste Materials
- *Bio-Treatment for Subgrade Stabilization*
- Blast Densification
- Bulk-Infill Grouting
- Chemical Grouting/ Injection Systems
- Chemical Stabilization of Subgrades & Bases
- *Column-Supported Embankments*
- Combined Soil Stabilization with Vertical Columns
- Compaction Grouting
- Continuous Flight Auger Piles
- Deep Dynamic Compaction
- Deep Mixing Methods

46 TECHNOLOGIES ADDRESSED *(CONT.)*

- Drilled/Grouted & Hollow Bar Soil Nailing
- Electro-Osmosis
- Excavation & Replacement
- Fiber Reinforcement in Pavement Systems
- Geocell Confinement in Pavement Systems
- Geosynthetic Reinforced Construction Platforms
- Geosynthetic Reinforced Embankments
- Geosynthetic Reinforcement in Pavement Systems
- Geosynthetic Separation in Pavement Systems
- Geosynthetics in Pavement Drainage
- Geotextile Encased Columns
- High-Energy Impact Rollers
- Hydraulic Fill + Vacuum Consolidation + PVDs
- Injected Light-Weight Foam Fill

46 TECHNOLOGIES ADDRESSED *(CONT.)*

- Intelligent Compaction
- Jet Grouting
- Light Weight Fills
- Mechanical Stabilization of Subgrades & Bases
- MSE Walls
- Micro-Piles
- Onsite Use of Recycled Pavement Materials
- Partial Encapsulation
- PVDs & Fill Preloading
- Rapid Impact Compaction
- Reinforced Soil Slopes
- Sand Compaction Piles
- Screw-In Soil Nailing
- *Shoot-In Soil Nailing*
- *Shored MSE Walls*
- Traditional Compaction
- Vacuum Preloading w/ & w/o PVDs
- Vibrocompaction
- Vibro-Concrete Columns

END USER PRODUCTS

- Main product: Web based information and guidance system
- Development project reports
- Within the system, for each of 46 technologies:
  - Technology Fact Sheets
  - Photographs
  - Case Histories
  - Design Procedures
  - Quality Control/Quality Assurance Procedures
  - Cost Estimating
  - Specifications
  - Bibliography

AUDIENCE

- Public agency personnel at local, state and federal levels
  - Primarily Geotechnical Engineers
  - Civil/Structural/Bridge Design & Construction Engineers, Pavement Design & Construction Engineers
  - Project Managers, Procurement, Research, Maintenance, District Engineers
- Consultants, General Contractors, A/E groups, Academics/Students

GOAL OF INFORMATION & GUIDANCE SYSTEM

To make geotechnical solutions more accessible to public agencies in the United States for rapid renewal and improvement of the transportation infrastructure.

"Project Vision"

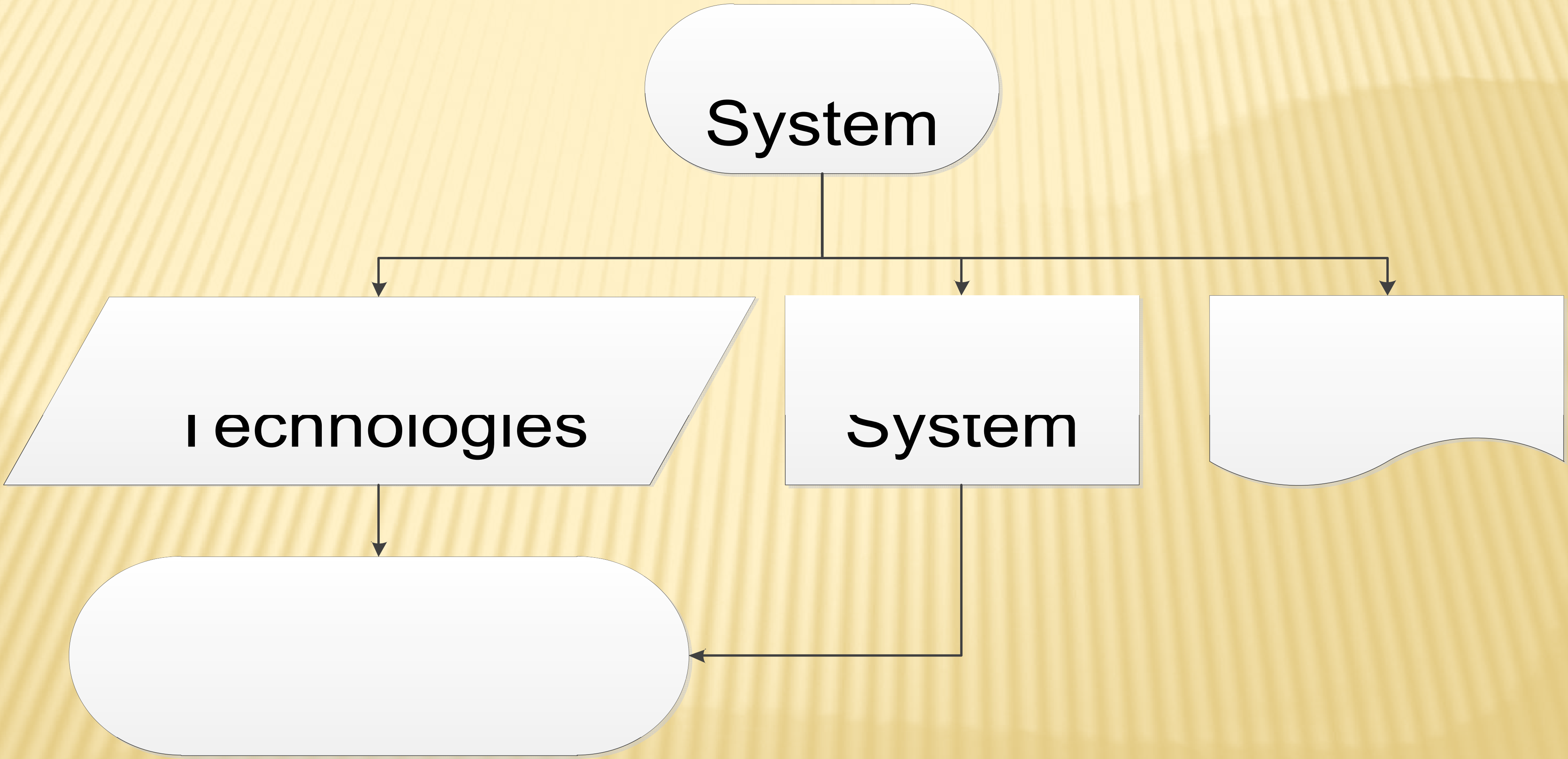
OBJECTIVES OF THE SYSTEM

1. Identify potential technologies for design and construction for the following transportation applications:
   - Construction over UNSTABLE soils
   - Construction over STABLE or STABILIZED soils
   - Geotechnical pavement components (base, subbase, and subgrade)
   - Working platforms

OBJECTIVES OF THE SYSTEM

2. Provide guidance to develop a 'short-list' of applicable technologies
3. Provide guidance for detailed project-specific screening of technologies with consideration of SHRP 2 Renewal Objectives
4. Provide an interactive, programmed system
5. Provide current, up to-date information

SYSTEM STRUCTURE



VALUE ADDED

- Main product: Web based information and guidance system
- The primary value of the system is that it ***collects***, ***synthesizes***, ***integrates***, *and* ***organizes*** a vast amount of ***critically important information*** about geotechnical solutions in a system that makes the information ***readily accessible*** to the transportation agency personnel who need it most.

STRATEGIC HIGHWAY RESEARCH PROGRAM

Accelerating solutions for highway safety, renewal, reliability, and capacity

Information and Guidance System

www.GeoTechTools.org

Expected to be open to public in November 2012

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Geotech Tools: Geo-construction Information & Technology Selection Guidance for Geotechnical, Structural, & Pavement Engineers was developed by a SHRP 2 project to make geotechnical solutions more accessible to public agencies in the United States. This website is a toolkit of geotechnical information to address all phases of decision making from planning to design to construction to allow transportation projects to be built faster, to be less expensive, and/or to last longer. Anyone involved in planning, design, and construction of transportation infrastructure will benefit from the information and resources available here. The information in the system is also applicable to non-transportation works and beyond the United States. We invite your comments and feedbacks on any aspect of the system. A *Users' Guide to the Information and Guidance System* is available. First time users are encouraged to review the User's Guide.

Geotechnical Design Process

Prior to technology selection, site-specific conditions and constraints must be identified. The geotechnical design process presents an overview of the considerations involved in evaluating site conditions and implementing a geoconstruction technology.

Catalog of Technologies

The Catalog of Technologies provides a listing of all the technologies. For each technology, the following information is available:

- Technology Fact Sheet
- Photos
- Case Histories
- Design Guidance
- QC/QA Procedures
- Cost Estimating
- Specifications
- Bibliography

Technology Selection

Technology Selection is an interactive tool to identify candidate technologies for specific geoconstruction applications using project information and constraints. Final technology selection requires project-specific engineering. Technologies can also be accessed by classification or through a catalog of specific technologies.

Glossary

This website contains technical terms and industry-specific jargon. A glossary has been compiled to assist in understanding the terminology used throughout this website and in its documents.

Release 1.0

This website and its contents were developed by the SHRP 2 R02 research team and is currently in its first release; TRB makes no representation or warranty of any kind (see disclaimers). We look forward to receiving your comments and suggestions.

Geotechnical Solutions for Transportation Infrastructure is a SHRP 2 project developed to make geotechnical solutions more accessible to public agencies in the United States. This website is a toolkit of geotechnical information to address all phases of decision making from planning to design to construction to allow transportation projects to be built faster, to be less expensive, and/or to last longer. Anyone involved in planning, design, and construction of transportation infrastructure will benefit from the information and resources available here.

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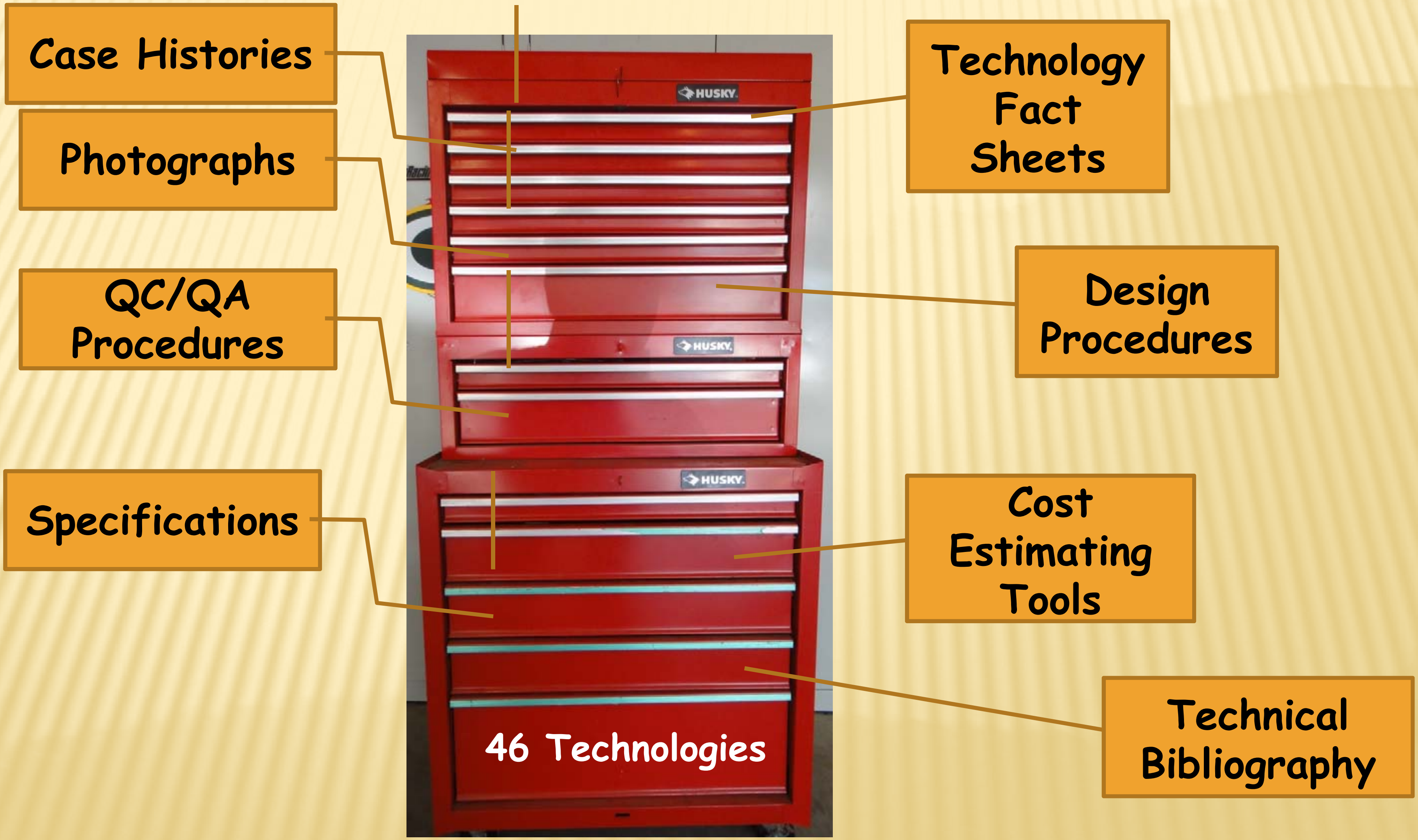

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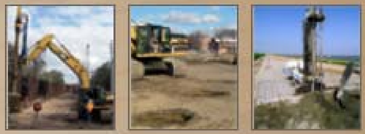
GEO-CONSTRUCTION INFORMATION & TECHNOLOGY SELECTION

GUIDANCE FOR GEOTECHNICAL, STRUCTURAL, & PAVEMENT ENGINEERS



SHRP2 STRATEGIC HIGHWAY RESEARCH PROGRAM

TRANSPORTATION RESEARCH BOARD OF THE NATIONAL ACADEMIES

Catalog of Technologies

About the Technologies Listed

Included are ground improvement and geoconstruction technologies that are used for the following elements of construction:

- New embankment and roadway construction over unstable soils
- Roadway and embankment widening
- Geotechnical pavement components (base, subbase, and subgrade)
- Working platforms

An exception is that two traditional technologies—excavation and replacement, and traditional compaction—are included as often used "base" technologies, to which ground improvement and geoconstruction methods are often compared.

Click here to view Catalog of Technologies with SHRP 2 R02 ratings that also allows comparison of selected technologies.

Technology
▶ Aggregate Columns
▶ Beneficial Reuse of Waste Materials
▶ Bio-Treatment for Subgrade Stabilization
▶ Blasting Densification
▶ Bulk-Infill Grouting
▶ Chemical Grouting/Injection Systems
▶ Chemical Stabilization of Subgrades and Bases
▶ Column-Supported Embankments
▶ Combined Soil Stabilization with Vertical Columns
▶ Compaction Grouting
▶ Continuous Flight Auger Piles
▶ Deep Dynamic Compaction
▶ Deep Mixing Methods
▶ Drilled/Grouted and Hollow Bar Soil Nailing

HOME
SHRP 2 R02 PROJECT BACKGROUND
GEOTECHNICAL DESIGN PROCESS
CATALOG OF TECHNOLOGIES
TECHNOLOGY SELECTION
GLOSSARY
ABBREVIATIONS
FREQUENTLY ASKED QUESTIONS
SUBMIT A COMMENT
SUBMIT A CASE HISTORY
LINKS
ABOUT THIS WEBSITE

Technology Information

Aggregate Columns

Aggregate column technology refers to both rammed aggregate piers and stone columns. Rammed aggregate piers are constructed by using a high-energy down-hole tamper to compact the aggregate and form the individual column elements. Stone columns are similar, but are constructed using a down-hole vibratory probe.

- Technology Fact Sheets
- Photos
- Case Histories
  - Office Building, Missouri
  - Slope Stabilization, New York
  - Liquefaction Potential Reduction, Missouri
  - Slope Rehabilitation, Washington, DC
- Design Guidance
- Quality Control/Quality Assurance
- Cost Information
- Specifications
- Bibliography

Check All | Clear

Downloading multiple documents

Check the individual boxes beside documents or use the "Check All" button to select the documents for download. After checking the desired documents, select the "Download Zip File" button at left to download your documents.

SHRP 2 ratings for Aggregate Columns

	Potential Contribution to SHRP 2 Renewal Objectives		
Degree of Technology Establishment	Rapid Renewal of Transp. Facilities	Minimal Disruption of Traffic	Production of Long-Lived Facilities
4	3	1	4

(Rating Scale: 1 = not established or low applicability, 5 = well established or high applicability)

See the SHRP 2 R02 Technology Ratings Summary for a legend and description of rating development.

Technologies

- Aggregate Columns
- Beneficial Reuse of Waste Materials
- Bio-Treatment for Subgrade Stabilization
- Blasting Densification
- Bulk-Infill Grouting
- Chemical Grouting/Injection Systems
- Chemical Stabilization of Subgrades and Bases
- Column-Supported Embankments
- Combined Soil Stabilization with Vertical Columns
- Compaction Grouting
- Continuous Flight Auger Piles
- Deep Dynamic Compaction
- Deep Mixing Methods
- Drilled/Grouted and Hollow Bar Soil Nailing
- Electro-Osmosis
- Excavation and Replacement
- Fiber Reinforcement in Pavement Systems
- Geocell Confinement in Pavement Systems
- Geosynthetic Reinforced Construction Platforms

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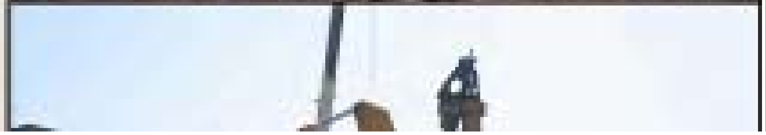
- [ ] Technology Fact Sheets
- [ ] Photos

Case Histories

- [ ] Office Building, Missouri
- [ ] Slope Stabilization, New York
- [ ] Liquefaction Potential Reduction, Missouri
- [ ] Slope Rehabilitation, Washington, DC

- [ ] Design Guidance
- [ ] Quality Control/Quality Assurance
- [ ] Cost Information
- [ ] Specifications
- [ ] Bibliography

Check All | Clear



SHRP 2 ratings for Aggregate Columns

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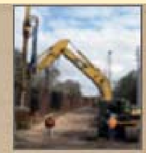

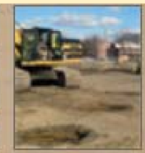

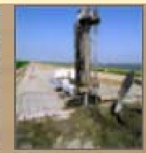

Glossary

A glossary was compiled to help users understand the terminology used throughout this information and guidance system. References for the glossary are found at the bottom of the page. Several key terminology compilations that can be accessed openly through the Internet are listed below.

- American Concrete Institute – Concrete Terminology
- Degen Engineering – Glossary of Ground Improvement Vocabulary
- Intelligent Compaction – Terminology and Glossary
- Pavement Interactive
- Pavement Recycling Guidelines for State and Local Governments Participant's Reference Book – Glossary
- Recycled Materials Resource Center – Glossary of Terms
- The Waste and Resources Action Programme – AggRegain
- University Of Utah Seismograph Stations – Earthquake Glossary
- User Guidelines for Waste and Byproduct Materials in Pavement Construction
- USGS Earthquake Hazards Program – Earthquake Glossary

The references below are linked to the sites to purchase the copyrighted compilations of terms.

- AASHTO M145–91: Standard Specification for Classification of Soils and Soil–Aggregate Mixtures for Highway Construction Purposes
- AASHTO M146–91: Standard Specification for Terms Relating to Subgrade, Soil–Aggregate, and Fill Materials
- ASTM C125 – 11: Standard Terminology Relating to Concrete and Concrete Aggregates
- ASTM D653 – 09: Standard Terminology Relating to Soil, Rock, and Contained Fluids
- Deep Foundations Institute: Glossary of Foundation Terms

A B C D E F G H I J K L M N O P Q R S T U V W X Y Z References

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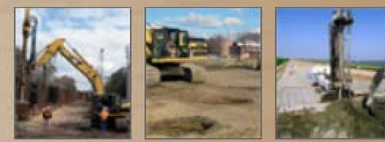

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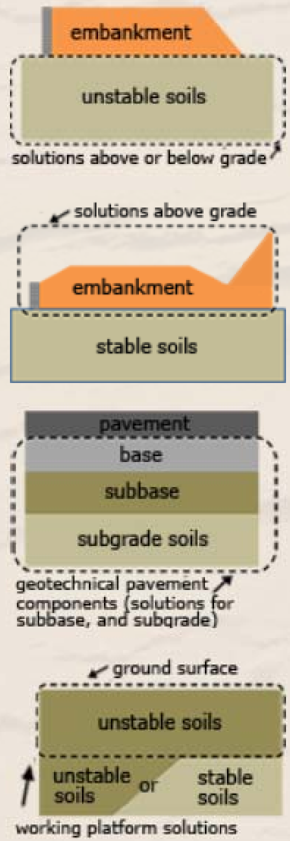
Interactive Selection System

Select an Application ?

Begin the interactive selection system by selecting one of the applications to the right. These inputs are the basic information required for screening potential technologies.

The technologies shown in the far right-hand column are all the potential solutions available in this system. After selecting one of the applications below, a short list of potential solutions for the selected application will appear in the right hand column. As additional inputs are entered, potential technologies are highlighted and eliminated technologies are faded.



- Construction over Unstable Soils
- Construction over Stable or Stabilized Soils
- Geotechnical Pavement Components (Base, Subbase, and Subgrade)
- Working Platforms

? *are found throughout the interactive selection system to provide additional information regarding each selection.*

Technologies

- Aggregate Columns
- Beneficial Reuse of Waste Materials
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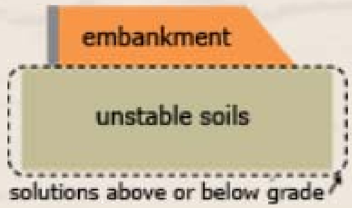
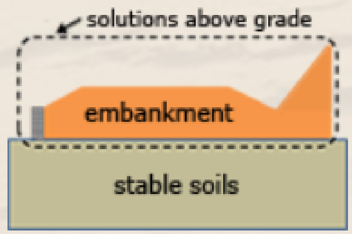
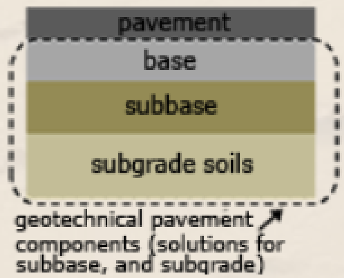


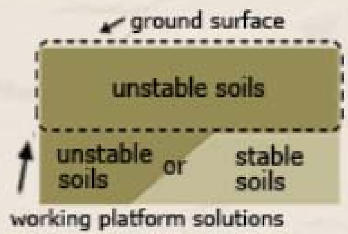
- Construction over Unstable Soils



- Construction over Stable or Stabilized Soils



- Geotechnical Pavement Components (Base, Subbase, and Subgrade)



- Working Platforms

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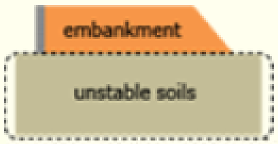
Each screen will prompt for an input. These inputs are the basic information required for screening potential technologies. The technologies shown in the right-hand column are potential solutions for the selected application. As additional inputs are entered, potential technologies are highlighted and eliminated technologies are faded.

Your selections so far

Click on an item to return to a previous selection.



▶ Selected Application	Construction over Unstable Soils

Select a response that best represents project conditions

◀ **return to previous selection**

Select Unstable Soil Condition

- Wet and Weak, Fine Grained Soils
- Unsaturated, Loose Granular Soils
- Saturated, Loose Granular Soils
- Voids – Sinkholes, Abandoned Mines, etc.
- Problem Soils and Sites – Expansive, Collapsible, Dispersive, Organic, Existing Fill, Landfills

**For guidance on combining technologies, see White Paper on Integrated Technologies for Embankments on Unstable Ground.*

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- Jet Grouting
- Lightweight Fill
- Micropiles
- Partial Encapsulation
- Prefabricated Vertical Drains and Fill Preloading
- Rapid Impact Compaction

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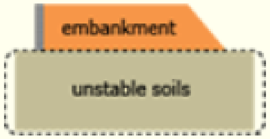


▶ Selected Application	Construction over Unstable Soils
▶ Unstable Soil Condition	Unsaturated, Loose Granular Soils

Select a response that best represents project conditions

return to previous selection

Depth below ground surface requiring treatment. This depth could be full-depth treatment of unstable soils or partial- depth treatment of unstable soils.

- 0 - 5 ft
- 5 - 10 ft
- 10 - 30 ft
- 30 - 50 ft
- Greater than 50 ft

**For guidance on combining technologies, see White Paper on Integrated Technologies for Embankments on Unstable Ground.*

? are found throughout the interactive selection system to provide additional information regarding each selection.

Technologies

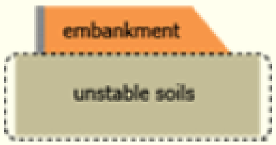
- **Aggregate Columns**
- **Blasting Densification**
- Bulk-Infill Grouting
- **Chemical Grouting/Injection Systems**
- **Column-Supported Embankments**
- **Combined Soil Stabilization with Vertical Columns**
- **Compaction Grouting**
- **Continuous Flight Auger Piles**
- **Deep Dynamic Compaction**
- **Deep Mixing Methods**
- Electro-Osmosis
- **Excavation and Replacement**
- Geosynthetic Reinforced Embankments
- Geotextile Encased Columns
- **High-Energy Impact Rollers**
- Injected Lightweight Foam Fill
- **Jet Grouting**
- Lightweight Fill
- **Micropiles**
- Partial Encapsulation
- Prefabricated Vertical Drains and Fill Preloading
- **Rapid Impact Compaction**

Interactive Selection System

Each screen will prompt for an input. These inputs are the basic information required for screening potential technologies. The technologies shown in the right-hand column are potential solutions for the selected application. As additional inputs are entered, potential technologies are highlighted and eliminated technologies are faded.

Your selections so far

Click on an item to return to a previous selection.



▶ Selected Application	Construction over Unstable Soils
▶ Unstable Soil Condition	Unsaturated, Loose Granular Soils
▶ Depth Below Ground Surface	30 - 50 ft

Select a response that best represents project conditions

return to previous selection

This completes the screening process. The highlighted technologies on the right are the candidate technologies based on these selected inputs.

Go to selection summary ?

Only proceed to project specific selection if you are experienced with selecting and implementing geoconstruction technologies.

Continue to project-specific selection ?

**For guidance on combining technologies, see White Paper on Integrated Technologies for Embankments on Unstable Ground.*

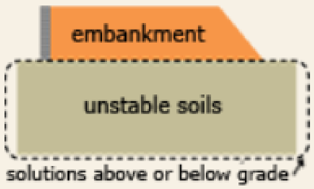
? are found throughout the interactive selection system to provide additional information regarding each selection.

Technologies

- ▶ **Aggregate Columns**
- ▶ **Blasting Densification**
- Bulk-Infill Grouting
- ▶ **Chemical Grouting/Injection Systems**
- ▶ **Column-Supported Embankments**
- ▶ **Combined Soil Stabilization with Vertical Columns**
- ▶ **Compaction Grouting**
- ▶ **Continuous Flight Auger Piles**
- Deep Dynamic Compaction
- ▶ **Deep Mixing Methods**
- Electro-Osmosis
- Excavation and Replacement
- Geosynthetic Reinforced Embankments
- Geotextile Encased Columns
- High-Energy Impact Rollers
- Injected Lightweight Foam Fill
- ▶ **Jet Grouting**
- Lightweight Fill
- ▶ **Micropiles**
- Partial Encapsulation
- Prefabricated Vertical Drains and Fill Preloading
- Rapid Impact Compaction

Project Characteristics

The project and site information input into the selection system is summarized below.



Selected Application: *Construction over Unstable Soils*

Unstable Soil Condition: *Unsaturated, Loose Granular Soils*

Depth Below Ground Surface: *30 - 50 ft*

Potential Technologies

The potential technologies as a result of the project and site information are shown below.

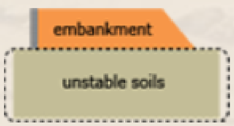
		Potential Contribution to SHRP 2 Renewal Objectives		
Technology	Degree of Establishment*	Rapid Renewal*	Minimal Disruption*	Long-Lived Facilities*
Aggregate Columns	4	3	1	4
Blasting Densification	3	3	2	4
Chemical Grouting/Injection Systems	3	3	4	4
Column-Supported Embankments	3	5	1	4
Combined Soil Stabilization with Vertical Columns	2	3	1	4
Compaction Grouting	4	3	3	3
Continuous Flight Auger Piles	4	4	1	4
Deep Mixing Methods	3	4	1	4
Jet Grouting	4	4	2	4
Micropiles	4	3	2	3
Sand Compaction Piles	2	4	1	3
Vibrocompaction	5	4	1	4
Vibro-Concrete Columns	3	4	1	4

*See the SHRP 2 R02 Technology Ratings Summary for a legend and description of rating development.

Interactive Selection System: Project-Specific Technology Selection for Construction over Unstable Soils

Selections Made

The following selections have been made so far. Click on an item to return to a previous selection.



Construction over unstable soils

Selected Application: Construction over unstable soils

Unstable Soil Condition: Unsaturated, Loose Granular Soils

Depth Below Ground Surface: 30 - 50 ft

Select Project-Specific Characteristics

Answer the following questions that best describe the site conditions. Leave questions blank when the information is unknown (at this time) or unapplicable. The list on the right will update as selections are made. Click on the ? for additional information regarding each selection.

? **Purpose of Improvement:**

---------- Make your selection ----------

? **Additional Purpose of Improvement:**

---------- Make your selection ----------

? **Select Project Type:**

---------- Make your selection ----------

? **Site Characteristics:**

---------- Make your selection ----------

? **Size of Area to be Improved:**

---------- Make your selection ----------

Technologies

- **Aggregate Columns**
- **Blasting Densification**
- **Chemical Grouting/Injection Systems**
- **Column-Supported Embankments**
- **Combined Soil Stabilization with Vertical Columns**
- Compaction Grouting
- **Continuous Flight Auger Piles**
- Deep Dynamic Compaction
- **Deep Mixing Methods**
- Electro-Osmosis
- Excavation and Replacement
- Geosynthetic Reinforced Embankments
- Geotextile Encased Columns
- High-Energy Impact Rollers
- **Jet Grouting**
- Lightweight Fill
- **Micropiles**
- Prefabricated Vertical Drains and Fill Preloading
- Rapid Impact Compaction
- **Sand Compaction Piles**
- Vacuum Preloading with and without Prefabricated Vertical Drains
- **Vibrocompaction**
- **Vibro-Concrete Columns**

PRODUCTS AVAILABLE FOR EACH TECHNOLOGY (INFORMATION TRANSFER)

Case Histories

Photographs

QC/QA Procedures

Specifications

Technology Fact Sheets

Design Procedures

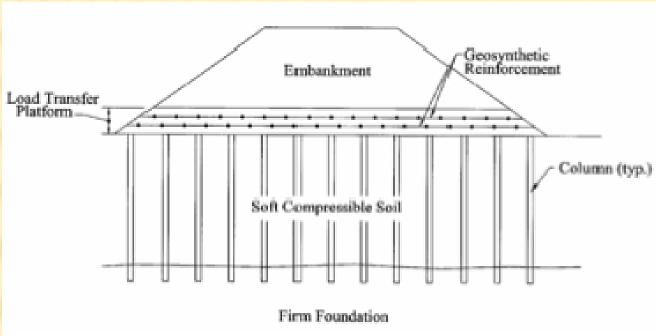
Cost Estimating Tools

Technical Bibliography

TECHNOLOGY FACT SHEET

COLUMN-SUPPORTED EMBANKMENTS

November 3, 2011



(after FHWA 2004)

Basic Function:
Column-Supported Embankments (CSE) enable construction of embankments over unstable soils by transferring the load to a stiffer underlying stratum.

Advantages:
- Accelerates construction compared to conventional methods
- Reduces total and differential settlement
- Protects adjacent facilities from distress
- Can be used with a wide variety of columns to accommodate different site conditions

General Description:
Column-supported embankments are used when the soil is too soft or compressible to support the embankment. The columns transfer the load to a firm stratum below the soft layer. The columns can be floating or end-bearing depending on the site geology, the project requirements, and the type of column used. For most CSE applications, the columns are end-bearing. When high-capacity columns with wide spacings are used, geosynthetic reinforcement is typically used at the interface between the top of the columns and the embankment to more efficiently transfer the embankment load to the columns.

Geologic Applicability:
- Typically used on soft compressible clay, peats, and organic soils where settlement and global stability are concerns
- Most cost effective when the compressible material thickness ranges from 15 to 70 feet (4.6 to 21.3 meters)
- Soft soil underlain by stiffer soil or bedrock

SHRP2 STRATEGIC HIGHWAY RESEARCH PROGRAM

Construction Methods: Columns of strong material are placed in the soft ground to provide the necessary support by transferring the embankment load to a firm stratum. There are numerous types of columns that may be used for this technology (e.g., aggregate columns, vibro-concrete columns, deep mixing method columns, continuous flight auger piles, driven piles with or without pile caps). A load transfer platform or bridging layer may be constructed immediately above the columns to help transfer the load from the embankment to the columns, and thereby permit larger spacing between columns than would be possible otherwise. Load transfer platforms generally consist of compacted soil and geosynthetic reinforcement. The important details of soil type and geosynthetic reinforcement used in the load transfer platform depend on the design procedure employed. Load transfer platforms are used more often when the spacing between columns is relatively large (i.e., greater than 6 feet), which requires higher load carrying capacity from the columns (e.g., vibro-concrete columns, continuous flight auger piles).

Additional Information: Load transfer platforms are also used to minimize differential settlement when the embankment height is low. Aggregate columns, because of their lower vertical load capacity, are often spaced close enough together that a load transfer platform is not required.

SHRP2 Applications:
- New Embankment and Roadway Construction
- Roadway and Embankment Widening

Example Successful Applications:
- Rancocas Creek Railroad Bridge – NJ
- I-95/Route 1 Interchange – Alexandria, VA
- Minnesota TH241 Widening – St. Michael, MN

Complementary Technologies: Many different column technologies can be used with CSEs. Some applications may use lightweight fill in combination with column supported embankments.

Alternate Technologies: Technologies for similar applications include preloading with or without PVDs, lightweight fill, excavation and replacement, staged construction, and geosynthetic reinforcement embankments.

Potential Disadvantages:
CSEs can incur a higher cost than technologies that require more time before the embankment can be put into service. CSEs suffer form a lack of standard design procedures and lack of knowledge about technology benefits, design procedures, and construction techniques.

Key References for this technology:

Collin, J.G. (2007). "U.S. state-of-practice for the design of geosynthetic reinforced load transfer platforms in column supported embankments." GeoDenver 2007. *GSP-172: Soil Improvement*. CD-ROM.

Filz, G. M. and Smith, M. E. (2007). "Net vertical loads on geosynthetic reinforcement in column-supported embankments." GeoDenver 2007. *GSP-172: Soil Improvement*. CD-ROM.

FHWA (2004). Ground Improvement Methods-Technical Summary #7: Column Supported Embankments. NHI Course No. 132034. FHWA NHI-04-001.

SHRP2 STRATEGIC HIGHWAY RESEARCH PROGRAM

COLUMN-SUPPORTED EMBANKMENTS (CSE)

Placement of geosynthetic reinforcement for column supported embankment (CSE) from FHWA (2004).

Placement of select fill for CSE from FHWA (2004).

PHOTOGRAPHS

Column Supported Embankment
Minnesota Trunk Highway 241 Widening
– Project Case History –

Location: TH 241 near St. Michael, MN, southwest of I-94/TH 241 interchange

Owner: Minnesota Department of Transportation

Contractor:

Engineers: MnDOT and The Collin Group

Year Constructed: 2006

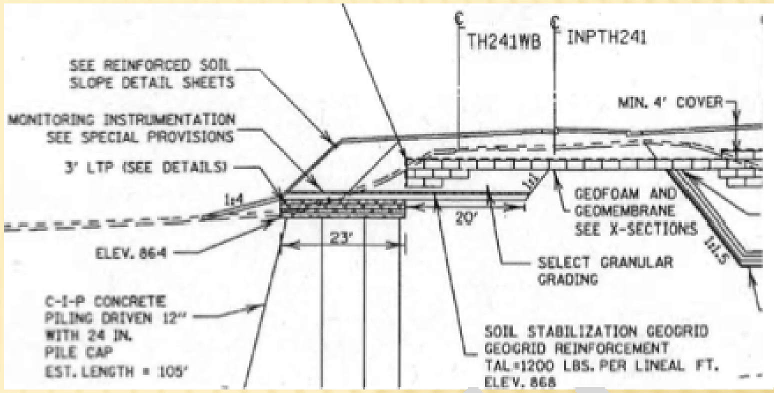
Project Summary/Scope:
A pile supported embankment was constructed on Trunk Highway (TH) 241 near St. Michael, MN, about 2,000 feet southwest of the I-94/TH 241 interchange. This project involved the widening of a highway from two to four lanes. The new embankment was a widening of an existing embankment. Differential settlement between the new embankment section and the old section was a concern.

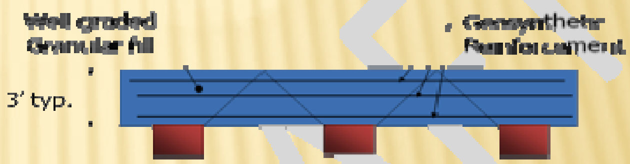
Subsurface Conditions: 30 feet of highly organic silt loams and peats underlain by 20 feet of silty organic soils. Below that is 12 feet of loamy sand underlain by 35 feet of gravelly sand. A well-cemented sandstone lay 100 feet below the ground surface. The section of highway is bordered on the northwest by a small pond and on the southeast by marshy terrain

Pile spacing was 7 feet on-center and the diameter of pile caps was 2 feet. The Load Transfer Platform (LTP) embankment was designed using the beam design method. Piles consisted of steel pipes filled with concrete. Four layers of geosynthetic reinforcement were used with granular fill. The total thickness of the LTP was 3 feet (~ 1 meter). Backfilling of the embankment was completed on October 10, 2006. Instrumentation data is presented through June 4, 2007.

Complementary Technologies Used:
Geofoam lightweight fill, reinforced soil slope, and geosynthetic construction platform stabilization technologies were also used for this embankment widening.

PROJECT CASE HISTORY





Performance Monitoring:
The embankment was instrumented with 48 sensors including strain gages, earth pressure cells, and settlement systems. Settlements, geosynthetic strains, and pile strains/loads are presented in the technical paper for an approximately 10-month period following construction. A finite element analysis was performed using STRAND7. Instrumentation results are compared with the finite element analysis.

Case History Author/Submitter:
Rich Lamb, P.E.
Foundations Engineer
MnDOT Office of Materials,
Mailstop 645
1400 Gervais Avenue
Maplewood, MN 55109

Rich.Lamb@dot.state.mn.us
(651) [illegible] - [illegible]

Project Technical Paper: Wachman, G.S., Biolzi, L. and Labuz, J.F. (2010). "Structural behavior of a pile-supported embankment," Journal of Geotechnical and Geoenvironmental Engineering, Vol. 136, No. 1, pp 26-34.

Date Case History Prepared: 3 November 2010

Case History Summaries

- Initially populated with 1 to 4 per technology
- Want more (many more)
- Soliciting submission from agency personnel, researchers, etc.
- See Submit a Comment for submittal and standard format

Preferred QC/QA Procedures

There are no FHWA approved QC/QA procedures for column supported embankments. Limited QC/QA information can be found in the FHWA Ground Improvement Manual, and there is some QC/QA information for geosynthetics, not specific to CSEs, in FHWA "Geosynthetic Design and Construction Guidelines."

Publication Title	Publication Year	Publication Number	Available for Download
Elias, V., Welsh, J., Warren, J., Lukas, R., Collin, J., Berg, R. "GROUND IMPROVEMENT METHODS REFERENCE MANUAL VOL. II"	2006	FHWA NHI-06-020	Yes[1]
Holtz, R.D., Christopher, B.R. and Berg, R.R. (2007). "GEOSYNTHETIC DESIGN AND CONSTRUCTION GUIDELINES"	2007	FHWA-NHI-07-092	Yes[1]

[1] These documents are available online for a fee at [illegible]

QC/QA Guidelines

QC/QA for a column supported embankment project should include verification of the properties and placement of the LTP fill, embankment fill, and the geosynthetic reinforcement. Very large projects may include a budget for an embankment test section. As more knowledge of column supported embankments is gained through case histories, numerical modeling, and the embankment tests for the SHRP2 R02 project, a need for test embankment sections, even for large projects, may be reduced. Some type of settlement and/or lateral displacement monitoring should be included to determine if the embankment performs as expected. Although not covered in this document, industry standard QC/QA procedures for the type of column or pile used for embankment support should be followed.

Pre-production embankment test sections should be considered only on very large projects or where a performance approach specification is used. For large projects, design validation is particularly useful, because a test section may lead to a more economical design. If a performance approach specification is used, then monitoring of the embankment test section will serve as the basis for an acceptable design. Typically the acceptance criteria are based on maximum total and/or differential settlement criteria.

Geosynthetics testing and verification should include:

- documentation of manufacturer, model number, lot number, and roll number for each roll
- verify the following properties of the geosynthetic per manufacturer's certified test results: ultimate strength per ASTM D 6637 (geogrid) or ASTM D 4595 (geotextiles), creep resistance per

SHRP2 STRATEGIC HIGHWAY RESEARCH PROGRAM

SHORED MSE WALL SYSTEMS

DESIGN GUIDANCE

Preferred Design Procedure:

The Federal Highway Administration (FHWA) has a set of design documents for this technology. The documents are summarized below.

Publication Title	Publication Year	Publication Number	Available for Download
Shored Mechanically Stabilized Earth (SMSE) Wall Systems Design Guidelines	2006	FHWA-CFL/TD-06-001	Yes[1]

[1] http://www.geotechnicaldirectory.com/publications/MSE-Wall/MSE-Wall-Design-Manual.pdf

Summary of Design/Analysis Procedure: FHWA Guidelines

Reference(s): *Berg, et al. (2009), Morrison, et al. (2006a), Morrison, et al. (2006b), Morrison, et al. (2006c), Morrison, et al. (2007)*

The FHWA guideline for the design of shored mechanically stabilized earth wall systems essentially follows the Morrison, et al. (2006b) method and incorporates the stabilizing effects of the shoring wall component in the design of the MSE wall component. This allows for a reduction of the reinforcement length from 0.7 times the height (H) of the wall to approximately 0.3H. In addition, sliding and overturning modes of failure are not analyzed for the MSE portion of the system as the shoring wall eliminates the driving forces. The internal stability of the MSE portion of the system considers the stability of the active wedge of soil based on the cumulative pullout of all layers of reinforcement that extend behind the failure surface.

The design methodology for a shored MSE wall is based on the design methodology of a regular MSE wall. After a thorough site investigation is performed, backfill material must be selected. The design guidelines in Morrison, et al (2006b) can only be used when select granular fill is used for the reinforced fill zone behind the MSE wall. Select granular material for SMSE walls must not contain organics or other deleterious materials, should be free draining and have a minimum friction angle of 34 degrees. In addition, the fill material should be free of shale and other soft, poor durability particles and have a sodium sulfate soundness loss of less than 15 percent after 5 cycles.

Using the results of the site investigation, a preliminary geometric configuration for the MSE wall system is determined (e.g., following the FHWA guidelines). This includes the MSE wall width and height, MSE wall vertical reinforcement type and spacing, shoring wall height, bench width in front of MSE wall and traffic surcharge load. Once the trial geometric configuration for the MSE wall system is chosen, the internal stability of the MSE wall component is evaluated. This includes addressing the failure mechanisms of soil reinforcement rupture and soil reinforcement pullout. This is done by:

- Estimating the location of the critical failure surface using Rankine's active earth pressure theory;

COST INFORMATION

Commentary

Typical contract pay items and units of measurement used for geosynthetic reinforcement in pavements include:

- Geosynthetic (fabric or grid) measured by the square yard in-place.
- Granular material measured by the ton.

The equipment used to construct geosynthetic reinforcement in pavements is common to highway construction projects; therefore, additional mobilization costs are negligible.

Cost Information Summary

The total labor and equipment cost associated with installation of geosynthetic reinforcement in pavements is minimal. Material cost of the geosynthetic makes up the vast majority of total cost. Production rates for the installation of geosynthetics are controlled by related construction activities (e.g. placement of base course(s) and paving). Equipment and labor resources are easily adjusted to match the production rate of controlling activities with little effect on total cost. The following table lists construction cost items which are associated with geosynthetic reinforcement in pavements, along with approximate cost ranges. Cost ranges are based on data from 2009 through 2010. Readers should carefully examine the project characteristics and constraints and determine to what degree, if any, these factors may influence the actual cost associated with constructing geosynthetic reinforcement in pavements.

Cost Information Summary

The total labor and equipment cost associated with installation of geosynthetic reinforcement in pavements is minimal. Material cost of the geosynthetic makes up the vast majority of total cost. Production rates for the installation of geosynthetics are controlled by related construction activities (e.g. placement of base course(s) and paving). Equipment and labor resources are easily adjusted to match the production rate of controlling activities with little effect on total cost. The following table lists construction cost items which are associated with geosynthetic reinforcement in pavements, along with approximate cost ranges. Cost ranges are based on data from 2009 through 2010. Readers should carefully examine the project characteristics and constraints and determine to what degree, if any, these factors may influence the actual cost associated with constructing geosynthetic reinforcement in pavements.

Pay Item Description	Quantity Range	Unit	Low Unit Price	High Unit Price	Factors Which May Potentially Impact Costs
Geosynthetic	Greater Than 5,000	SY	$1.00	$5.00	• Geogrids are more expensive than fabrics • Woven fabrics are more expensive than nonwoven fabrics • Heavier fabrics cost more • Smaller dimension grids and heavier grids cost more • Specified lap widths impact the total quantity of material required • Production rates do not significantly affect unit costs

COST INFORMATION

Historical Cost Information

A sample of actual project costs is shown in the table below.

Pay Item Description	Quantity	Unit	Low Unit Price	High Unit Price	Average Unit Price	No. of Bids	Bid Date	Source/Agency
Reinforcement Grid (Biaxial, Type 2)	90,023	SY	$2.53	N/A	N/A	1	07/29/2009	Florida DOT
Geogrid Base Reinforcement	72,000	SY	$1.00	$2.40	$1.79	10	06/05/2009	Arizona DOT
	28,100	SY	$1.75	$3.25	$2.21	9	06/12/2009	
	5,735	SY	$1.60	$3.50	$2.22	6	09/25/2009	
Stabilization Geotextile, Special	12,320	SY	$146	$4.80	$2.55	12	03/05/2010	Michigan DOT
	3,210	SY	$2.45	$3.25	$2.65	4	10/01/2010	
Geotextile Stabilization	32,367	SY	$0.84	$1.46	$1.15	6	03/25/2010	New York DOT
	5,200	SY	$1.09	$2.51	$1.58	8	05/20/2010	
	13,459	SY	$1.05	$2.51	$1.46	7	06/10/2010	
Special – Geogrid, Type P2 (WT:06)	6,300	SY	$3.36	$3.52	$3.44	2	07/15/2010	Ohio DOT

Conceptual Cost Estimating Tool

Click here to open a cost estimating spreadsheet for producing a preliminary project scoping estimate.

Conceptual Estimating Tool - Geosynthetics in Pavement Systems

Notes to User:

A. This estimating tool is provided as a means to perform an initial project scoping estimate. Use for any other purpose is strongly discouraged. The accuracy and reliability of the estimated costs are highly dependent upon the user inputs, care should be taken to adjust inputs for specific project characteristics. The user assumes all risks associated with the cost estimates produced by this estimating tool.

B. Guidance on unit cost ranges and potential impacts on cost is provided in the cost information summary for each technology. Users are responsible for determining appropriate unit costs.

C. Cells highlighted in "burnt orange" require user input.

D. Cells with "maroon" colored text are automatically calculated, but may be manually overridden by the user.

1. Calculate the Surface Area of Geosynthetic Reinforcement

Length (ft):	5,280
Width (ft):	50
Area (yd^2):	29,333

2. Estimate the Quantity of Granular Material

Thickness of Granular Layer (in):	12
Estimated Density of Granular Material (lb/ft^3):	120
Total Quantity of Granular Material (ton):	15,840

3. Estimated Cost of Geosynthetics in Pavement Systems - Refer to Cost Information Summary for Typical Unit Cost Ranges and Impacts on Unit Prices

	Unit Cost	Quantity	Cost
Geosynthetic Reinforcement (yd^2):	$ 3.00	29,333	$ 88,000
Granular Material (ton):	$ 10.00	15,840	$ 158,400
Estimated Total Cost of Geosynthetic in Pavement Systems:			**$ 246,400**
Estimated Unit Cost of Geosynthetic in Pavement Systems ($/yd^2):			**$ 8.40**

Conceptual Estimating Tool - Prefabricated Vertical Drains and Fill Preloading

Notes to User:

A. This estimating tool is provided as a means to perform an initial project scoping estimate. Use for any other purpose is strongly discouraged. The accuracy and reliability of the estimated costs are highly dependent upon the user inputs, care should be taken to adjust inputs for specific project characteristics. The user assumes all risks associated with the cost estimates produced by this estimating tool.

B. Guidance on unit cost ranges and potential impacts on cost is provided in the cost information summary for each technology. Users are responsible for determining appropriate unit costs.

C. Cells highlighted in "burnt orange" require user input.

D. Cells with "maroon" colored text are automatically calculated, but may be manually overridden by the user.

1. Calculate the Surface Area Where PVDs are to be Installed

Length (ft):	2,000
Width (ft):	150
Area (ft²):	300,000

2. Estimate the Total Quantity of PVDs to be Installed

Design output information required - Preliminary PVD grid spacing and average depth of installation are necessary for this step

Estimated Longitudinal Grid Spacing of PVDs (ft):	5.00
Estimated Transverse Grid Spacing of PVDs (ft):	5.00
Number of PVDs to be Installed:	12,431
Average Depth of PVD Installation (ft):	50
Total Quantity of PVDs (lf):	621,550

3. Estimate the Drainage Layer Quantity - Complete One of the Options Listed

Design output information required - Drainage layer type and volume/spacing characteristics are necessary for this step

Granular Material Option:	
Thickness of Granular Drainage Layer (in):	-
Approximate In-Place Density of Granular Drainage Layer (lb/ft³):	110
Total Quantity of Granular Drainage Layer (ton):	-
OR	
Horizontal Strip Drain Option:	
Estimated Longitudinal Spacing of Horizontal Strip Drain (ft):	5
Total Quantity of Horizontal Strip Drain (lf):	60,000

4. Optional Depending Upon Soil Conditions - Estimate the Quantity of Augering Through Stiff Upper Soil Strata

Estimated Thickness of Stiff Soil Requiring Augering (ft):	10
Number of Augered Holes (ea):	12,431
Total Quantity of Augered Holes (lf):	124,310

5. If Needed, Estimate the Materials Required for an Initial Working Platform

Length (ft):	2,000
Width (ft):	150
Quantity of Geosynthetic for a Working Platform (yd²):	33,333
Optional, Thickness of Granular Layer for Working Platform (in):	6
Optional, Estimated Density of Granular Material for Working Platform (lb/ft³):	120
Total Quantity of Granular Material for Working Platform (ton):	9,000

6. Optional, Estimate the Surcharge Volume Required

Design output information required - Surcharge volume is dependent upon the desired settlement rate

Average Surcharge Length (ft):	2,000
Average Surcharge Width (ft):	150
Average Surcharge Height (ft):	10
Total Surcharge Volume (yd³):	111,111

7. Estimate Additional Embankment due to Settlement and/or the Surcharge Volume to be Removed (wasted)

Design output information required - Estimated amount of settlement is needed

Surcharge removal is reduced by the estimated settlement - there is no additional cost attributable to PVDs when the surcharge removal can be utilized in an embankment on the project

Estimated Settlement (ft):	4
Optional, Total Surcharge Volume to be Wasted (yd³):	66,667

8. Estimated Cost of PVDs - Refer to Cost Information Summary for Typical Unit Cost Ranges and Impacts on Unit Prices

	Unit Cost	Quantity	Cost
Optional, Geosynthetic for Working Platform (yd²):	$ 2.75	33,333	$ 91,667
Optional, Granular Material for Working Platform (ton):	$ 10.00	9,000	$ 90,000
PVD Unit Price ($/lf):	$ 1.00	621,550	$ 621,550
Mobilization (lump sum):	$ 15,000.00	1	$ 15,000
Granular Drainage Layer ($/ton):	$ 15.00	-	$ -
OR			
Horizontal Strip Drain ($/lf):	$ 1.00	60,000	$ 60,000
Optional Pre-Augered Holes ($/lf):	$ 8.00	124,310	$ 994,480
Surcharge Embankment ($/yd³):	$ 4.00	111,111	$ 444,444
Additional Embankment Due to Settlement, Applies if No Surcharge is Constructed or if Settlement Exceeds Surcharge Height ($/yd³):	$ 4.00	-	$ -
Surcharge Excavation ($/yd³) and (yd³):	$ 4.00	66,667	$ 266,667
Estimated Total Cost of PVD Installation:			**$ 2,583,808**
Estimated Unit Cost of PVD Installation for Area Treated ($/ft²):			**$ 8.61**

SUMMARY

- Knowledge base for 46 ground improvement and geoconstruction technologies and a web-based information and guidance system have been developed to facilitate and organize this knowledge so that informed decisions can be made.
- The value of the system is that it collects, synthesizes, integrates, and organizes a vast amount of critically important information about ground improvement solutions in a system that makes the information readily accessible to the user – and is readily updatable.

QUESTIONS?

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