Presentation Program Outline

1. Conventional Construction Materials Facility Design / Operational / Permitting Issues
2. Description of Alt. Materials Properties
3. Applications of Alt. Material for Flood Facilities
4. Construction / Installation Requirements
5. Design Analysis Procedures / Criteria
6. Advantages / Disadvantages / Costs
7. CASE STUDY
   San Juan Creek Jet Grouting Revetment
Conventional Flood Control Facility Construction Material / Design
Common Categories of Flood Control Facilities

- Detention
- Retention
- Sedimentation
- Infiltration
- Dikes

- Open Channel
- Pipes
- Bridges
- Culverts
- Levees

- Storage
- Conveyance
- Energy Dissipation

- Diversion / Complex Structures
- Erosion Protection
- Invert Stabilization
# Conventional Floodplain / Channel Revetment Material Options

<table>
<thead>
<tr>
<th>RIGID</th>
<th>FLEXIBLE</th>
<th>BIOENGINEERED VEGETATIVE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete slope lining (ABM)</td>
<td>Loose rock rip-rap</td>
<td>Live staking</td>
</tr>
<tr>
<td>Grouted rock rip-rap</td>
<td>Gabions</td>
<td>Brush layering</td>
</tr>
<tr>
<td>Soil cement</td>
<td>Articulating concrete block (ACB)</td>
<td>Brush mattress</td>
</tr>
<tr>
<td>Roller compacted concrete</td>
<td>Geotextile soil reinforcement systems</td>
<td>Willow poles</td>
</tr>
<tr>
<td>Sheet piles</td>
<td>Soil retention</td>
<td>Live facines</td>
</tr>
</tbody>
</table>

**Advantages**

- **RIGID**
  - Eliminates lateral erosion of bank
  - Limited maintenance requirements
  - Limited uncertainty of hydraulic
  - High velocity applications

- **FLEXIBLE**
  - Erosion resistance only
  - Ability to adjust to changes in the foundation material

- **BIOENGINEERED VEGETATIVE**
  - More naturalized system
  - Compatible with existing stream habitat
  - Sustainable system
  - Facilitates environmental permitting

**Disadvantages**

- **RIGID**
  - Deep embedment below scour depth
  - Potential barrier to permeability and vegetation
  - Must have suitable foundation for installation
  - May reflect flow energy
  - Structural system

- **FLEXIBLE**
  - Limiting maximum resisting velocity
  - More surface area installed on a flatter slope.
  - Not soil retaining or soil loads
  - Greater encroachment into the waterway

- **BIOENGINEERED VEGETATIVE**
  - Requires establishment period for growth
  - Both hydraulic and biological requirements
  - Limited knowledge plant hydraulic resistance
  - Hydraulic forces may not be compatible with vegetation success
Rigid Revetment / Channel System

Construction Materials

- **Concrete Slope Lining**
  - Abrasion / Erosion Resistance
  - Steeper Vertical Geometry
  - Higher Velocity Resistance
  - Earth Retaining Structures (some)

- **Reinforced Concrete Cantilever Wall**
  - Lower Roughness Values
  - Reduced R/W Requirements
  - Reduced Maintenance
  - Reduced Streambed Footprint Impact

- **Grouted Rock Rip-Rap**

- **Soil Cement**

- **Roller Compacted Concrete**

- **Sheet Piles - Steel/Concrete**
Common Facility Design Issues Related to Material Selection
Common Failure Modes / Operational Issues Revetment Systems

- **MATERIAL EROSION / ABRASION**
- **FOUNDATION SETTLEMENT / UPLIFT**
- **HYDROSTATIC PRESSURE / PIPING**
- **SCOUR / UNDERMINING / OVERTOPPING / FLANKING**
Construction / Installation Issues with Flood Control Systems Materials

- Accessibility / Site Limitations
- Excavation / Shoring
- Dewatering
- Environmental Mitigation / Restrictions
- Material / Equipment Availability
- Existing Facilities / Utilities
Physical / Regulatory Constraints
Limiting Design Solution

Geotechnical
Environmental Streambed Impacts
Floodplain Hydraulics

Regulatory Permitting
Sediment Transport / Erosion
Streambank Geometry / Space Limitations
Alternative Construction Materials
## Alternative Construction Materials for Flood Protection Facilities

<table>
<thead>
<tr>
<th>MATERIAL DESCRIPTION</th>
<th>BENEFITS</th>
</tr>
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<tbody>
<tr>
<td>JET GROUTING / DEEP SOIL MIXING</td>
<td>- Insitu ground modification to create “soil crete” by injecting stream of high velocity grout moving soil and mixing with grout</td>
</tr>
</tbody>
</table>
| VINYL / FRP SHEET PILES | - No excavation  
- No dewatering  
- Deep below ground foundation  
- Geometry adjusts to force/loads  
- Rigid system |
| MECHANICALLY STABILIZED EARTH (MSE) SYSTEM | - Light weight  
- Easy field modify lengths  
- Non-corrosive  
- Long service life  
- Low material cost  
- Recyclable materials |
|                      | - Low costs  
- Structural reinforcement  
- Simple construction  
- Minimal footprint to stream  
- High structural load capacity  
- Seismic Resistance  
- Limited foundation requirements |
Vinyl / FRP Sheet Piles - Overview

Benefits

- Lower costs
- Chemical inertness
- Weatherability
- Strength
- Impact properties
- Easy field adjustments
- Inert materials/sustainable

Disadvantages

- Yield strength not as high as steel
- Abrasion resistance
- Drive-ability rock / stiff soils
MSE Wall Systems - Overview

• Structural reinforcing using **Geogrid mats**
  o HDPE horizontal grid panels or meshes (Tensar®)
  o Carry tensile load in two directions transferred from soil bearing pressure
  o High structural integrity / load capacity
  o Resists degradation and harsh environments
  o Meshes layout are either **Biaxial** and **Uniaxial**

• Horizontal reinforcing elements extend into soil mass
  Retained earth functions similar to gravity wall
• “Segmental Wall” on earthen face can be used that are interlocking for vertical wall geometry
  o Transfer horizontal soil loading on panel to attached geogrid
MSE Wall Systems - Overview

Benefits

- Can be use for bioengineered reinforced banks
- Allows much steeper than normal slope face
- Much lower cost alternative to reinforced wall systems
- Ability to resist higher loads - seismic and soil
  - Difficult to achieve safety factor for seismic loads with conventional reinforced concrete walls
- Constructed as part of earthwork operation
- Reduces foundation requirements difficult to achieve for most structural systems in riverine environment
  - Higher differential settlement acceptable
  - Bearing Loads transferred to horizontal reinforcement so foundation stability not as critical
Jet Grouting / Deep Soil Mixing
• **Jet Grouting** is a versatile Ground Modification system used to create in situ cemented geometries of soilcrete.

• Jet Grouting accomplishes this by the injecting a stream of high velocity grout stream into the formation to disaggregate the soil and mix it with grout.

Scour Protection  
Impermeable Shafts
Jet Grouting – In-situ Soilcrete Ground Stabilization for Continuous Gravity Wall
Jet Grouting – In-situ Soilcrete Ground Stabilization for Continuous Gravity Wall
Jet Grouting Column Installation Process

- Insertion of jetting tools into a drilled hole
- Injection of high-velocity cement slurry and air
- Completion of a subsurface Super-Jet Column
“High Pressure” Injection Grouting
Different Types of Grout Injection Systems – One to Three Fluids

- **Single Fluid**
  - Single Rod
  - Monitor (typ)

- **Double Fluid**
  - Double Rod
  - Air Grout

- **Triple Fluid**
  - Triple Rod
  - Air Water

Jet Grouting Diameters and Drilling Pattern Layout for Continuous Wall

Typical Scallop Pattern to Achieve Overlap – Plan View Layout

Super Jet

10’ – 16’

Double
3’ – 8’

Triple
3’ – 4’

Single
1’ – 3’
Variety of Factors Influence Final Strength of Soilcrete Column

- Soil
  - Soil Stiffness
  - pH
- Binder
  - Type
  - Injection Rate
  - W:C ratio
  - Additives
- Equipment
  - Method
    - 1
    - 2
    - 3 SJ
  - Pull Rate
  - Rotation Rate
  - Nozzle Size
Primary Influence of Jet Grouting Strength Soil Type

- Final soilcrete strength factor for structural load design and abrasion resistance
- Requires laboratory test mixing first to evaluate actual anticipated range
- Comparing to soil cement generally require greater than 750 psi for revetment design applications
Equipment for Jet Grouting Installation

- **Track Mounted Drill Rig**
- **Grout Mixer / Cement Silo**
- **Grout Pump**
Construction Quality Control Items Field Monitoring

• Objective – Are **Specified and Design Properties** being Met?
  • Strength
  • Geometry
    • **Diameter**

• Field Monitoring
  • Monitor Injection Parameters
    • Flow rate
    • Pressure
    • Grout Properties
  • Grout return
  • Wet Grab Samples
  • Coring
Quality Control of Strength Wet Samples and Coring of Columns

Cored Sample

Wet Sample
## Characteristics Involved in Selection of Jet Grouting Alternative - Benefits

<table>
<thead>
<tr>
<th>DISADVANTAGES</th>
<th>ADVANTAGES</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cost</strong></td>
<td><strong>Surgical</strong></td>
</tr>
<tr>
<td>o Cement intensive system</td>
<td>o Treat specific areas</td>
</tr>
<tr>
<td>o Cost can vary wildly based on application</td>
<td>o Work around utilities, other U/G structures</td>
</tr>
<tr>
<td>o Economies of scale may offset</td>
<td>o Relatively quick process</td>
</tr>
<tr>
<td><strong>Spoils</strong></td>
<td><strong>Column size</strong></td>
</tr>
<tr>
<td>o Generally messy worksite</td>
<td>o Independent of rig</td>
</tr>
<tr>
<td>o Spoils need to be handled, moved off site.</td>
<td>o 9 inch hole – 16 foot diameter column.</td>
</tr>
<tr>
<td><strong>Heave</strong></td>
<td>o Small footprint</td>
</tr>
<tr>
<td>o Uncontrolled grouting can heave ground (vertical and lateral), structures</td>
<td><strong>Process works in all soil types</strong></td>
</tr>
<tr>
<td><strong>Strength</strong></td>
<td><strong>In-situ Process</strong></td>
</tr>
<tr>
<td>o Lower compressive strength than other systems</td>
<td>o Avoids excavation for deep foundations</td>
</tr>
<tr>
<td>o Not as abrasion resistance</td>
<td>o Avoids dewatering</td>
</tr>
<tr>
<td>o Designed as gravity wall requires more material/ massive</td>
<td></td>
</tr>
</tbody>
</table>
Structural Design

- Designed as unreinforced “gravity wall”
- Criteria on ACOE EM 1110-2-2502 Engineering Design – Retaining and Flood Walls
- Stability based on (1) sliding, (2) overturning, and (3) bearing for minimum safety factors from ACOE guidance

<table>
<thead>
<tr>
<th>Design Criteria</th>
<th>Sliding - Minimum Factor of Safety</th>
<th>Overturning - Minimum Factor of Safety</th>
<th>Maximum Allowable Bearing Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1..33</td>
<td>1.5</td>
<td>3,000 psf</td>
<td></td>
</tr>
</tbody>
</table>
Case Study – San Juan Creek Streambank Revetment – Jet Grouting (Orange County, CA)
Regional Watershed Map

Legend
- Regional Node
- Main Stream
- Streams
- Regional Watersheds
- Upstream Watersheds
- Rancho Mission Viejo Boundary

UPSTREAM WATERSHEDS
67,800 Acres
106 SQ. Miles
Q100 = 40,800 cfs
Revetment Design for New Bridge Replacement Scour/Erosion Protection
Detailed Fluvial Analysis Resulted in High Scour Depths

- Local abutment scour dominated
- Cyclic in-nature because of high sediment delivery – “transport-limited” reach of creek
Selected Composite Revetment Section
– Jet Grouting and Soil Cement
Bridge Revetment Layout – East Bank

- West Revetment (see Figure 01)
- Concrete over jet grout per plans
- Maint. Rd. Sta 34+92.67 to 34+92.87
- 8" concrete cap over 12" soil cement (see section hereon)
- Maint. Rd. Sta 29+02.26 to Sta 30+52.67
- 4" A.C. over 16" soil cement (see section hereon)
- 4" A.C. over 4" A.B. (see Sheet 3A of 40)
- 9" concrete cap over 4" A.B.
- Maint. Rd. Sta 34+92.34 to Sta 37+02.49 (see Sheet 3A of 40)

Flow

San Juan Creek Channel

East Revetment 1" = 40'
Bridge Revetment Layout – West Bank

West Revetment

Water Flow
Revetment Jet Grout Columns Layout – Achieves Structural Design Width

Design Layout for “Effective Width”

Detailed Column Plan
Peak of Scour/Flowrate:
- 100-year maximum scour
- HWE 100-year in creek
Immediately after storm hydrograph:
• Assumes 1/2 total scour remained although unlikely
• HWE drops to Original Stream Invert
Structural Design Load Case No. 3 – After Storm Low Scour Hole / No Water

Completely after scour event:
- Assumes ¼ total scour remained although unlikely
- HWE drops below jet grout column
Field Construction Installation Process

Jet Grout Columns Ortega Highway
Field Construction Installation Process

Jet Grout Columns Ortega Highway
Revetment Performance January 2015
Storm Event
Summary – Alternative Construction Materials

- Alternative construction materials provide additional options for engineer’s “toolkit”
- May provide more cost-effective solutions than conventional materials
- Ability to address more difficult regulatory permitting constraints
- Provides project solution where non may not have been available previously
- Ability to address unique construction and structural loading constraints
APPLICATION OF NEW ALTERNATIVE CONSTRUCTION MATERIALS FOR FLOODPLAIN PROTECTION

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