Introduction

- Speaker Introduction
- Audience Background
- Today’s Topics
  - Why Ground Improvement
  - Dynamic Compaction
  - Lightweight Fill
  - Wick Drains
  - Stone Columns
• Increase Bearing Capacity / Control Deformation
  ◦ Site Conditions
    • Uncontrolled Fills
    • Loose Sands
    • Under Consolidated Clays
  ◦ Strategies
    • Deep Dynamic Compaction
    • Vibro Compaction
    • Surcharge / Wick Drain
    • Stone Columns
    • Geosynthetics
    • Soil Mixing / Grouting

Why Ground Improvement?

• Accelerate Consolidation
  ◦ Site Conditions
    • Compressible Fine-Grained Soils
    • Uncontrolled Fill
  ◦ Strategies
    • Surcharge Loads
    • Wick Drains
    • Dynamic / Vibro Compaction

Why Ground Improvement?
Why Ground Improvement?

- Decrease Imposed Loads
  - Site Conditions
    - Under Consolidated Fine-Grained Soils
    - Underlying Loose Granular Materials
  - Strategies
    - Lightweight Fill
    - Geosynthetics

Why Ground Improvement?

- Lateral Stability / Seepage Cutoff / Liquefaction
  - Site Conditions
    - Under Consolidated Fine-Grained Soils
    - Permeable Granular Soils
    - Silt Soils Above Water Table
  - Strategies
    - Surcharge
    - Wick Drains
    - Grouting
    - Stone Columns
    - Soil Mixing
Dynamic Compaction

- **Description**
  - Application of high levels of energy at the ground surface

- **Methodology**
  - Crane and Tamper
  - Free Fall Drop on Grid Pattern
  - Drop Height of 40 feet to 60 feet
  - Tamper Weight of 10 tons to 20 tons
  - Tamper Diameter ~ 5 feet

- **Typical Application**
  - Densification of Loose / Uncontrolled Fills
  - Collapse of Large Voids
  - Liquefaction Control
  - Effective Depth ~ 20 Feet
Dynamic Compaction

Advantages
- Tamper serves as probe & correction tool
- Densification observed during work
- Same equipment over range of materials
- Uniform bearing to minimize differential settlement
- Perform during inclement weather

Disadvantages
- All material compacted is not observed
- Ground vibrations
- Utilities / buried structures
- Granular soil types above water table

Dynamic Compaction

Feasibility Evaluation
- Degree of Saturation
- Presence of Hard/Weak Layers
- Permeability of Soil Mass (Zones I, II, and III soils)
  - Zone I \( \rightarrow \) permeability > $1 \times 10^{-3}$ cm/sec – clean sands (good)
  - Zone II \( \rightarrow \) permeability $1 \times 10^{-3}$ to $1 \times 10^{-6}$ cm/sec + Plastic Index < 8 + unsaturated – silty sands (marginal)
  - Zone III \( \rightarrow \) permeability < $1 \times 10^{-6}$ cm/sec + Plastic Index > 8 (not suitable)
• **Vibrations**

  - Design
    - Depth & Degree of Improvement
      - Tamper Weight
      - Height of Drop
    - Energy Requirements
      - Applied Energy
      - Grid Spacing
      - Number of Drops
    - Specification
      - Performance (Degree of Improvement)
      - Monitoring & Verification
    - Cost
      - $1.00 - $2.50 per square of surface area

Dynamic Compaction
Lightweight Fill

- Types
  - Recycled Materials
    - Tire Chips
    - Wood / Saw Dust
    - Fly Ash
    - Boiler Slag
  - Manufactured Materials
    - Geofoam
    - Expanded Clay or Shale
• Typical Applications
  ◦ Reduce stress on soft soils (settlement)
  ◦ Reduce driving forces (retaining wall / slopes)
  ◦ Reduce seismic inertia forces
  ◦ Limited weather restrictions

• Limitations
  ◦ Availability
  ◦ Durability
  ◦ Environmental
  ◦ Geothermal Properties

Lightweight Fill

<table>
<thead>
<tr>
<th>Type</th>
<th>Density (pcf)</th>
<th>Approximate Cost $/cu. yd. (FHWA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Typical Soil (wet)</td>
<td>125 - 140</td>
<td>--</td>
</tr>
<tr>
<td>Geofoam (EPS)</td>
<td>0.6 – 2.0</td>
<td>25 – 50 (Plant)</td>
</tr>
<tr>
<td>Foamed Concrete</td>
<td>20 – 50</td>
<td>40 – 65</td>
</tr>
<tr>
<td>Shredded Tires</td>
<td>40 – 60</td>
<td>15 – 25</td>
</tr>
<tr>
<td>Expanded Shale/Clay</td>
<td>40 – 90</td>
<td>30 – 45 (Plant)</td>
</tr>
<tr>
<td>Fly Ash</td>
<td>70 – 90</td>
<td>10 – 20</td>
</tr>
<tr>
<td>Wood Fiber</td>
<td>40 – 65</td>
<td>10 – 15</td>
</tr>
<tr>
<td>Boiler Slag</td>
<td>60 – 115</td>
<td>5 – 10</td>
</tr>
</tbody>
</table>
Lightweight Fill - Geofoam

Manufactured Cellular Materials - Geofoam
- Expanded or Extruded Polystyrene (EPS / XPS)

Design
- Compressive Strength ~ 2.5 psi to 16 psi @ 1-5% strain
- Density ~ 0.6 to 2.0 pcf → up to 6.0 pcf water adsorption
- Coefficient of Lateral Earth Pressure ~ 0.1 vertical
- No decay in ground
- Buoyancy
- Petroleum / Geomembrane

Construction
- Leveling Course
- Interlock joints w/ mechanical connection
- Cover immediately due to wind, sun, buoyancy

Lightweight Fill - Foamed Concrete

Manufactured Foam Mixed On-Site
- Add preformed foam (shaving cream) to cement-water slurry

Design
- Compressive Strength - 110 psi to 150 psi varies w/ density
- Density - 20 to 50 pcf
- Use below freeze-thaw
- Buoyancy

Construction
- Need staging area
- Very fluid → tight forms and/or polyethylene
- 2 to 5 feet lift thickness (heat of hydration impacts foam)
- 12-hour wait between lifts
**Manufactured Expanded Clays & Shales**
- Heated 1,800 to 2,200 degrees Fahrenheit
- No clay mineral rehydration under atmospheric conditions
- Expensive to manufacture
- Granular material behavior (no compressive strength)

**Design**
- Angle of Shearing Resistance ~ 37 to 44 degrees
- Density ~ 40 to 90 pcf
- Coefficient of Lateral Earth Pressure ~ 0.27
- Adsorb water after placement (4-5 times placement %)
- Two feet thick soil cover

**Construction**
- Steel tracks breakdown – use rubber tires
- Use lightweight equipment to spread

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**Lightweight Fill – Exp. Clay/Shale**

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**Recycled Tires**
- Typically shredded into 3.0 to 8.0 inches particles (no crumb rubber)
- Granular material behavior (no compressive strength)

**Design**
- Angle of Shearing Resistance ~ 19 to 25 degrees
- Density ~ 40 to 60 pcf
- Coefficient of Lateral Earth Pressure ~ 0.26 to 0.47
- May leach metals in acidic conditions
- Spontaneous Combustion (Limit to lifts to 10 feet thick)
- Keep above water table / good drainage to avoid seepage
- Filtration Geotextile for adjacent soils
- Exposed wires (removed or 98% covered)

**Construction**
- 35% volume reduction during compaction
- 10% volume reduction with final cover

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**Lightweight Fill – Shredded Tires**
Recycled Material from burning process
- Fly Ash → Finer airborne particles (Class C or F)
- Slag → Larger Particles that fall to bottom

Design
- Potentially Expansive! (sulfate & entriginite)
- Angle of Shearing Resistance ~ 33 to 42 degrees
- Density ~ 40 to 90 pcf
- Fly Ash is compressible / Slag is granular
- Fly Ash alkaline leachate (pH 6.2 to 11.5)

Construction
- Fly Ash similar to silt
- Slag similar to sandy or gravelly material

Lightweight Fill – Fly Ash / Slag

Recycled Wood Waste from Sawmill
- Hog Fuel (bark), sawdust, and planer chips
- Geographically limited
- Degradation as exposed to oxygen

Design
- Leachate Acidic (pH 4-6) & May Contain Toxins
- Spontaneous Combustion Potential
- Angle of Shearing Resistance ~ 25 to 49 degrees
- Density ~ 40 to 90 pcf
- Two Feet thick surface cover

Construction
- Fly Ash similar to silt
- Slag similar to sandy or gravelly material

Lightweight Fill – Wood
Surcharge / Wick Drains

• Settlement Drivers (Fine-Grained Soils)
  ◦ Load
  ◦ Drainage
Surcharge

- Increase Load on Compressible Layer
- Accelerate Drainage
- Accelerate Time

Design

- Material Availability
- Dead Weight (Typically Soil, Concrete, Topsoil)
- Soil Wet Weight 125 to 140 psf per foot of height
- Time Estimates

Construction

- Excess Soil Disposal
- Instrumentation

**Surcharge**
Wick Drains

- Methodology
  - Install drains in subsurface
  - Decrease drainage path
  - Sand Drains (similar application)
  - Prefabricated Vertical Drains

- Applicability
  - Low Permeability Soil
  - Fully Saturated
  - Silts, Clays, Sludges, etc.
  - Liquefaction Reduction
  - Not used for highly organic soils / creep settlement
**Wick Drains**

- **Feasibility**
  - Install drains in subsurface
  - Sand Drains
  - Prefabricated Vertical Drains
  - Decrease Drainage Path

- **Applicability**
  - Low Permeability Soil
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**Wick Drains**
Stone Columns

- **Description**
  - Install backfill material (stone/concrete) at discrete intervals
  - Tightly interlocked with surrounding soil

- **Methodology**
  - Vibro-Replacement (Wet / Top-Feed / Jetting / Spoils)
  - Vibro-Displacement (Dry / Top or Bottom - Feed / No Spoils)

- **Typical Application**
  - Increase Bearing Capacity / Control Settlement
  - Liquefaction Mitigation
  - Slope Stability

Stone Columns
Stone Columns

- Advantages
  - Use shallow foundations
  - Ground Supported Floor Slab
  - Alternative to overexcavation and replacement
    - Shallow Groundwater
    - Environmental Concerns
    - Lower Vibrations

- Disadvantages
  - Obstructions
  - Lateral Ground Displacement
  - Very Soft Strata / Peat

Stone Columns

- Design Concepts
  - Composite Shear Strength of Soil-Stone Column
  - Area Replacement Ratio (10-40%)
  - Spacing (5.0 -10 FT) & Diameter (1.5-3.0 FT)
  - Stress Ratio (equal deformation)
• Alternate Systems
  ◦ Vibro-Replacement Concrete Columns (~ CMCs)
    ◦ Same as driven or bored pile
    ◦ Granular mat with geosynthetics
    ◦ Not connected to structure
  ◦ Geopiers
    ◦ Same design concept as general stone columns
    ◦ Ramming actions improves stone strength
    ◦ Higher Stiffness Ratio (up to 10 for columns, 6 for slopes)
    ◦ Minimum replacement ratio of 33%

QUESTIONS?

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