ODOT Geotechnical Information Exchange Seminar

Ground Improvement

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Outline

• Ground Improvement Overview
• Grouting
• Densification Techniques
• Vibro Technologies
Ground Improvement Overview
Goal of Ground Improvement

- Modify Soil Properties
  - Strength
  - Stiffness/Compressibility
  - Permeability
Typical Applications

• Provide Resistance to Liquefaction
• Minimize Settlement
• Incr. Bearing Capacity
• Create Seepage Barriers/Provide Drainage
• Stabilize Dispersive, Collapsing or Expansive Soils
• Fill Voids
• Improve Stability of Slopes
Methods of Ground Improvement

• Soil Replacement
• Admixture Stabilization/In Situ Mixing
• Dynamic Compaction
• Grouting - Compaction/Jet, etc.
• Drains
• Vibro Technologies
• Structural Reinforcement
• Freezing
• Light Weight Fill
Every pile load tested to 600 kips.

- Sands
- Silts
- Clays
Grouting
GROUTING DEFINITION

• Improvement of soil or rock through injection of chemicals or cementitious materials
Hussin, J.D., Degen, W.S.

Short Course on Soil Densification, Geo-Odyssey 2001
Compaction
Grouting
Compaction Grouting

• Soil improvement involving the injection, under relatively high-pressure, of a stiff grout to displace and compact soils

• The injected grout pushes the soils to the side as it forms a grout column or bulb
Compaction Grouting
Hussin, J.D., Degen, W.S.

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Compaction Grouting—Applications

- Reducing liquefaction potential
- Arresting foundation settlement
- Lifting and leveling structures
- Pre-construction site improvement
- Settlement control over tunnels or sinkholes
When is it typically used?

- Soil compaction near existing buildings and underground services, where vibratory methods are not practical
- Very small compaction projects, where the mob/demob cost of vibro equipment is prohibitive
- Many low cost providers
- Low headroom
Compaction Grouting

Bridge Foundations

Compaction Grout Bulb

Zone of influence of tunnel construction

Tunnel

FHWA-SA-98-086R
Compaction Grouting
Compaction Grouting - Limitations

- Limited use in coarse grained gravels where grout cannot be prevented to enter the soil pores
- Cohesive soils that will remold or where injection causes build up of pore water pressures
Compaction Grouting - Considerations

- Effective in loose granular soils, loose unsaturated fine-grained soils, collapsible soils and void filling
- Grout must have high internal friction, to ensure bulbs preserve “spheroidal” shape in the soil
- Less than 2-inch slump
- Greater than 3,000 psi compressive strength
Soil Mixed Walls/Columns

- Full groundwater cutoff
- Minimal vibration (drilled)
- Can be made permanent with facing
- Larger soldier piles add stiffness
- Convenient anchor attachments
Triple Head Augers
SOIL MIXED WALLS
SOIL MIXED WALLS

STEP 1: PRIMARY HOLES

STEP 2: PRIMARY HOLES

STEP 3: SECONDARY HOLES

STEP 4: INSTALL PILES PRIMARY HOLES

LEGEND:
- ◯ HOLE BEING DRILLED
- ○ PREVIOUSLY DRILLED HOLE
- I SOLDIER PILE ADDED TO HOLE
CSO Project
Corona, NY
Jet Grouting

High-pressure jets of cement grout are discharged sideways into the borehole wall to simultaneously excavate and then mix with the soil.
DEFINITION: Jet Grouting

• The process of creating soil-cement in place with a stabilizing grout mix delivered at pressure through nozzle(s) at the end of a monitor inserted in a borehole. The soil-cement is created by lifting and rotating the monitor defined above at slow, smooth, constant speeds, cutting and mixing the soil with grout and air.
JET GROUTING PROCEDURE SELECTION

• Soil Type - permeability, strength
• Objective - strength gain, water cut-off
• JET GROUTING
  • Erosion - improve wide range soils
  • Geometry - treat selected depth interval
  • Equipment - flexible / mobile track rigs
  • Groundwater - effective above & below GWT
  • Properties - continuous cemented soil mass
Test Program Guidelines

**Constants**
- Nozzle size
- Pressure
- Bentonite to water ratio

**Variables**
- Replacement ratio
- Extraction Rate
- Rotation
- Cement to water ratio
Sample Jetting Parameters

- 5.5 mm nozzle
- 4 cm lifts
- 25 sec/cm
- 94 strokes/min
- 400 bar grout
GROUTING / JET GROUTING

GROUTED SOIL PROPERTIES

- Strength
  - Gravels 700 to 3000 psi
  - Sands 700 to 2000 psi
  - Silts 300 to 1000 psi
  - Clays 75 to 700 psi

- Permability $10^{-6}$ TO $10^{-9}$ ft/sec
EXCAVATION SUPPORT APPLICATIONS

JET GROUTED INVERT (Kicker) SLABS

• Invert Treatment Prior to Excavation
• Groundwater Cut-Off
• Lateral Resistance
• Enhanced Construction
  • Reduced bracing in excavation
  • Stable invert platform
EXAMPLE A

- Ground Water Table
- Anchors (or optional internal bracing)
- Vertical Sheeting (soil mix walls, diaphragm walls, or steel sheet piles)
- Subgrade
- Jet-grouted Bottom Slab
- Water Pressure
EXAMPLE B

- Ground Water Table
- Anchors (or optional internal bracing)
- Vertical Sheeting (soil mix walls, diaphragm walls, or steel sheet piles)

*Subgrade*

*Soil*

*Grouted Hydraulic Cutoff Slab*

*Water Pressure*
O’Hare Airport

EXISTING GRADE

EL. 194.5M

2.28M WATER MAIN

3.65M RCP SEWER (TYP)

LIMIT OF JET GROUTED ZONE

EL. 183.9M

20.3M
Hussin, J.D., Degen, W.S.

Short Course on Soil Densification, Geo-Odyssey 2001
Vibro Technologies

- Stone Columns
- Vibro Compaction
- Vibro Concrete Columns
Vibro Technologies
Goals

• Densification
• Reinforcement
• Homogenization
• Load Transfer (VCCs only)
• Drainage
Benefits

• Increased Bearing Capacity
• Reduction of Total and Differential Settlement
• Expedites Consolidation Settlement
• Liquefaction Mitigation
Common Types of Facilities

- Dams/Embankments/Levees
- Waterways/Ports/Harbors
- Buildings, Tanks, Structures
- Roads/Bridges
- Waste Disposal/Containment Sites
Vibratory Probe

Isolator

Eccentric Weight
Vibrating Pokers

Power: 117 to 306 kW

Frequency: 30 to 60 Hz

Tip amplitude: up to 22 mm (1 inch)

Diameters: 200 to 400 mm (8 to 16 inches)

Length: Variable

Compressed air/jetted water

Bottom feed/concrete flots

NICHOLSON
Electronic Monitoring

Rapid information transfer across the world

100% quality control

Client confidence

Can record numerous variables to suit contract e.g.:
  - depth
  - packing-penetrating pressures
  - verticality
  - stone consumption
  - concrete pressure
  - time
  - pump pressure
Vibrated Stone Columns

Stone Column
A continuous vertical dense column of interlocking aggregate grains, free of non granular inclusions.

Vibrodisplacement
Stone column construction using compressed air and no water flush.

Vibroreplacement
Stone column construction using water flush.
Installation Methods

Top Feed Dry

Bottom Feed Dry/Wet

Top Feed Wet

Marine Techniques
Crane-Mounted
Wet Top Feed
**Vibro Replacement Summary**

- Similar to Vibro Compaction, Except Stone is Added
- Installed in Soft Silty or Clayey Sands, Silts and Clayey Silts
- Typical Improvement: 3-4 ksf,
- \( S = 1 \text{ inch}, \ S_{\text{diff}} = 1/300 \text{ to } 1/500 \) (0.5 inches), 40-60 kips/Column
Stone Columns - Benefits

Cohesive
- shear strength governing factor
- mostly consolidation
- long drainage path (d)

Loose Granular
- immediate settlement
- liquefaction induced settlement
- inundation settlement (fill)

Reinforced Cohesive
- stone column stiffness
- mostly immediate settlement
- reduced drainage path (d')
- pore pressure release

Densified Granular
- increase in soil density
- reduced immediate settlement
- reduced liquefaction potential
- reduction in potential inundation settlement (can be opposite)

Benefits of Stone Columns
- improved bearing capacity
- reduced settlements
- accelerated settlements
Area Replacement Ratio Concept
Stress Distribution
Rigid Fndn.

Po - Applied foundation load
Pp - Maximum (pile) stress
Stress Distribution - Stone Columns

$P_o$ - Applied foundation load

$P_c$ - Maximum (stone column) stress

$P_s$ - Minimum (soil) stress
Stone Column – Failure Mode
Bearing Pressures

Achievable post treatment bearing pressures are dependent on:

a. Soil type

b. Column diameter (vibrator type/method of installation) or column density ($A_o/A_c$ ratio)

Typical bearing pressures:

Dry method - up to 150 kPa (3100 psf) for soft cohesive soils
- up to 250 kPa (5200 psf) for granular soils

Wet Method - up to 250 kPa (5200 psf) for soft cohesive soils
- up to 400 kPa (8500 psf) for granular soils
Priebe (1995)

Graph showing the relationship between improvement factor $n$ and area ratio $A/A_c$ for different values of $\varphi_c$.

- $\varphi_c = 45.0^\circ$
- $\varphi_c = 42.5^\circ$
- $\varphi_c = 40.0^\circ$
- $\varphi_c = 37.5^\circ$
- $\varphi_c = 35.0^\circ$

The data points are labeled with $\mu_s = 1/3$. 
Determination of Densification - Greenwood
Soil Suitability

Zone B
stone columns

Zone A
deep compaction
Difficult Ground Conditions

Very soft clays with $C_u$ values < 15 kPa (310 psf)

Peat/degradable fills (refuge)

Obstructions and voided ground (made ground/natural)

Fills susceptible to collapse/inundation settlements

Non-engineered cohesive fills (<10 years)

Contaminated soils

Shrinkable soils

Backfilled pits/ quarries or variable fill thickness
Stone Columns:  
Control Testing – tests used to evaluate the workmanship/quality of stone column construction e.g. plate load tests, electronic monitoring of stone consumption and packing pressures, aggregate tests.

Load Testing – tests used to evaluate the bearing capacity and settlement characteristics of stone column/soil system e.g. medium to long duration, large plate tests, zone tests.

Stone Columns/Vibro Compaction:  
Density Testing – tests used to check the improvement in density of granular soils. Pre and post testing should be done e.g. CPT, SPT.
Vibro Compaction
Zone Test
<table>
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<th>Site</th>
<th>TILBURY</th>
<th>Rig No:</th>
<th>R1</th>
<th>Date:</th>
<th>28/03/01</th>
<th>Finish time:</th>
<th>11:01:35</th>
<th>Column No:</th>
<th>2379</th>
<th>Operator:</th>
<th>K.HILL</th>
<th>Max Pressure</th>
<th>184</th>
<th>Max Depth:</th>
<th>7.8</th>
</tr>
</thead>
</table>

![Pressure (Bars) vs Time (Seconds)](chart1)

![Depth (Meters) vs Time (Seconds)](chart2)
**Vibro Compaction**

- Effective for Sands, Silty Sands, and Gravelly Sands with less than 20% Fines
- After Penetration to Full Depth, Slowly Retrieve Probe in 12 to 18 in increments to allow for backfill placement
- Backfill is typically Sand or Gravel with less than 10% fines (No Clay)
- Typical Improvement is: $N = 17-25, \ Dr = 65-85\%$
• Every pile load tested to 600 kips
Vibrated Concrete Columns
Vibrated Concrete Columns

Concrete piles installed using vibrator technology

Mainly designed for axial loads typically up to 600 kN (135 kips)

Limited lateral load capacity

Where end bearing stratum is granular densification occurs generating improved carrying capacity

Enlarged basal bulb can be generated to increase carrying capacity

Enlarged heads up to 750 mm (30 inches) diameter can be provided to reduce span requirements of floor slabs
Concrete Columns – Installation
Concrete Columns – Slab Design

- Fully Suspended Floor Slab
- Ground Bearing Floor Slab (Incorporating a geo-matress)
**Vibro Summary**

- Consider overall foundation costs as opposed to cost of foundation elements alone
- Wide range of ground conditions
- Disposal concerns
- Homogenization
Band Drains

Installation depths: up to 20 m (66 feet)

Production rates: up 4,500 linear m per day (15,000 linear feet per day)
Dynamic Compaction

• Ground improvement through applying high levels of energy at the ground surface
• Repeated tamping of the ground using a 8-12 ton weight dropped from a crawler crane at heights of 50-100 ft
Dynamic Compaction
**Dynamic Compaction**

- Dynamic compaction is carried out in several passes. The weight is dropped repeatedly in a predetermined grid pattern.
- Enhances the geotechnical properties of the soil by the closure of void spaces.
- Compression of 5-10% of treated depth is typical.
Applications

• Liquefaction Potential Reduction
• Compacting weakly cemented sands in arid regions susceptible to collapse
• Densification of loose fill/granular deposits
• Void collapsing – Fills
• Karst
Dynamic Compaction – Suitable Soils

- Most commonly old fills and granular virgin soils
- Silts and some clays
Dynamic Compaction-Advantages

- Economical solution
- Can be used at sites with a very heterogeneous mixture of deposits
- Densification can be achieved below the water table
- Impacting the tamper into the soil serves as a probing and correcting tool
Dynamic Compaction - Disadvantages

- High levels of vibration
- Generally, dynamic compaction is not used within 100 – 150 ft of existing structures
- During Dynamic Compaction, careful monitoring of adjacent structures is necessary