Rigid Inclusions for Support of Roadways on Challenging Soils

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### Rigid Inclusions

#### Treatable Soil Types
- Soft clays & silts
- Controlled & uncontrolled fills (including landfills)
- Peat & other organic soils
- Loose sand & gravel
- Brownfield/contaminated sites

#### Structures
- Embankments, MSE walls, Abutments
- Industrial, residential, commercial & retail buildings
- Large distribution warehouses
- Oil storage tanks
- Wind turbines
- Utilities and pipelines
TYPICAL QUALITY CONTROL MEASURES

• On-Board monitoring
• Single-element load testing
• Material testing (Grout, LTP)
• Pile Integrity Testing (PIT)
• On-site engineers
Quality Control

- Onboard rig computer system that continuously monitors installation
- Real-time data:
  - Downward Pressure (crowd)
  - Rotary Pressure & Torque
  - Rate of Penetration & Extraction
  - Grout Pressure
  - Theoretical Profiles of Grouted RI’s
- Installation logs are easily accessible and reviewed daily
  - Submitted to client frequently
Rigid Inclusion vs. Piles

100% of the load in the piles. No load in the soil.

Share of the load between column and soil.
Rigid Inclusions vs. Piles for Embankment/Wall Support

Piles & Pile Caps

Rigid Inclusions
Rigid Inclusions – Support for MSE walls and Embankments
Rigid Inclusion : System Design

Four (4) main components must be designed in together to **optimize** the overall system:

- Load transfer platform
- Rigid Inclusions
- Soil matrix
- Structure / slab

Optimized designs by adapting spacing and diameters to account for varying:

- Soil conditions
- Loads
- Cut/Fill history
Uniform Load (Building / Embankment)

- Load Transfer by Arching
  - 5 - 30% of load on soil

- Load Transfer by Skin Friction
  - 70 to 95% of load in RI

- Limited settlement

Load Transfer Platform

Controlled Modulus Columns
Rigid Inclusion : Load Sharing Principles

Load-bearing layer

Q_P(0)  Q_P(0)  q_s  Q_P(z)

Load @ top of Rigid Inclusion

NEGATIVE SKIN FRICTION

POSITIVE SKIN FRICTION
Settlement Assumptions

Equal Settlement Planes / Strain compatibility
Lateral expansion of column
Load transfer is function of area replacement ratio

GRANULAR INCLUSIONS

Equal plane strain
Load transfer through arching
Load transfer through negative skin friction

RIGID INCLUSIONS
Estimating Settlement with Rigid Inclusions

- Calculation of settlements for rigid inclusions is not as straightforward as granular inclusions
  - Modulus is several orders of magnitude different
    - No strain compatibility
    - Complex soil-structure interaction
- Not Piles!
  - Sharing of the load with the soil
Design and FEM Modeling

STANDARD DESIGN APPROACHES

- Plaxis finite element software
  - 2D axisymmetric models
  - 2D plane strain models
  - Global 3D models
- Slope/global stability software
- L-PILE
- In-house design spreadsheets
2D Finite Element Method Analysis using Plaxis 2D

- Models symmetric 1-D compression
- Assumes lateral confinement at symmetric boundaries
- Valid for inclusions under uniform loading (embankments, slabs, large storage tanks)
- Good for:
  - confirmatory analyses
  - straight-forward design cases
  - refinement of spacing
  - evaluating sensitivity
- **Limitations:** edge effects and non-uniform loading conditions can’t be considered
3D Finite Element Method Analysis using Plaxis 3D

Advantages:
- Able to evaluate lateral deformation
- Uniform or variable loads
- Captures edge effects and 3-D effects
- Direct output of forces, stresses and moments in the rigid inclusions

Disadvantages:
- Computation time can be significant
- More effort to build and validate model
RIGID INCLUSIONS – Bearing capacity

Existing soil has a bearing capacity based on its in-situ shear strength

Additional bearing capacity derived from the RI’s, which results in overall system capacity

- Shallow bearing capacity is not counted – only the deeper bearing capacity from skin friction
- Based on diameter and spacing of RI’s
Embarkment Stability – Granular Inclusions

The block of equivalent improved soil is shown in light blue.

\[ \tau_{eq} \cdot A = \tau_{sc} \cdot A_{sc} + \tau_{soil} \cdot (A - A_{sc}) \]
\[ \tan(\varphi_{eq}) = m \cdot \tan(\varphi_{sc}) + (1 - m) \tan(\varphi_{soil}) \]

with
\[ m = \frac{A_{sc}}{A} \cdot \Delta q_{sc} + (1 - \frac{A_{sc}}{A}) \cdot \Delta q_{soil} \]
The rigid inclusion provide three effects:

1. **Unloading** of the soils between the inclusions
2. **Increased shear resistance** along the failure plane
3. **Vertical force** across the failure plane similar to soil nailing
Rigid Inclusions – Lateral Displacement

**Lateral Displacement Evaluations**
- Bester ES (Test Program)
- South Capital St. Bridge (Utility/Stormwater)
- 4th & 7th Brooklyn (for MTA Tunnel)
- Grand Ave, ILDOT (XYZ Survey for Duct bank movement)
- MNDOT (TPI – in prog)

**SUMMARY OF EXPERIENCE:**
- Effects of displacement are localized – can often maintain adequate clearance to avoid negative impact
- Methods for eliminating/reducing risk
  - Partial or Full replacement augering
  - Preauger locations

![Diagram of lateral displacement evaluations](image-url)
RIGID INCLUSIONS – BID UNITS AND COSTS

**Mobilization** – Lump Sum Per Each

**Testing** (Modulus/PIT/Strength) – Per Each
- Multiple Diameters
- Varying Embedment Layers

**Installation**
- Variables include Depth, Load, Diameter, Drilling Conditions, Project size, Working conditions (winter, tight work area, material supply)
  - $/SY - $75 to $750 SY (~$200/SY is common)
    - Consider LOADING or DEPTH variation
    - Use different pay items for each zone
  - $/LF - $15-$60
    - Consider DIAMETER or DRILLING conditions
  - **Lump Sum**
    - Need to define add/deduct rates for change in base scope of work
RIGID INCLUSIONS – CHALLENGES IN THE HIGHWAY MARKET

**Geotechnical**
- # of Borings
- Testing/Soils Data
- Responsibility of Selecting soil data (Owner vs. Specialty sub)

**Design**
- Tender period – Often too short
  - Coordination w/ GCs, Wall Suppliers, Earthwork

**Specifications**
- Design Build Performance Spec is preferred, w/ clear requirements for
  - Settlement (MSE vs Embankment vs Abutment Zones) and TIME!!!
  - FS - Bearing Capacity/Stability
  - Verification testing – frequency and when performed
  - Obstructions
QUESTIONS?