Alternative Deep Foundations to Enhance Sustainability of Infrastructure Projects

Kimberly Martin, PE (Arizona State University/CBBG)
Ranjiv Gupta, PhD, PE (Geosyntec)
Hamed Khodadadi T., PhD, PE (Arizona State University/CBBG)

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Outline

• Background
• Example Case
• Motivation
• Existing Method Limitations
• Existing Alternatives
• Future Alternatives
• Contributing to Circular Economy
Geotechnical Engineering

- Sub-discipline of Civil Engineering
- Involves evaluating, designing, and analyzing how the earth interacts with systems/structures
  - Using the earth to build and support infrastructure (pavements, pipelines, embankments, etc.)
  - Enhancing the earth to support structures (buildings, bridge abutments, transmission towers, excavation support etc.)
  - Evaluating soil properties to support geoenvironmental and hydrology design and analysis (soil ability to transmit fluids)
Supporting Structures: Foundations

- **Shallow Foundations**: Lightly loaded structures, deformable structures, and/or strong soil
  - Construct without specialized equipment
  - Preferred foundation type where possible
  - Materials are recoverable

- **Deep Foundations**: Heavily loaded structures, deformation limited structures, and/or weak soil
  - Construct with specialized equipment
  - Typically more expensive
  - Materials are difficult to recover

Example – Office Building in Austin, TX

• 10-story building under construction

• Superstructure
  – Floor Slabs
  – Walls and Columns
  – Joists and Beams

• Foundation
  – Drilled Piers of 2.5, 4.0 and 5.0 feet diameter
  – Depth of penetration 25 feet
  – Total 50 drilled piers
Concrete Usage – Office Building in Austin, TX

<table>
<thead>
<tr>
<th>Building Element</th>
<th>Volume</th>
<th>% of Total Concrete</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>cubic yards</td>
<td></td>
</tr>
<tr>
<td>Superstructure</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Floor Slabs</td>
<td>509</td>
<td>4%</td>
</tr>
<tr>
<td>Walls and Columns</td>
<td>2,336</td>
<td>20%</td>
</tr>
<tr>
<td>Joist and Beams</td>
<td>8,298</td>
<td>70%</td>
</tr>
<tr>
<td>Foundation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Drilled Piers</td>
<td>657</td>
<td>6%</td>
</tr>
<tr>
<td>Total</td>
<td>11,800</td>
<td>100%</td>
</tr>
</tbody>
</table>

Roughly 5-7% of concrete in building is used for foundation construction.
Material Reuse and Recovery – Office Building in Austin, TX

- **Superstructure**
  - Can be salvaged after the building is past its useful life

- **Foundations**
  - Recovery is not practical: Embodied energy to excavate site exceeds the beneficial results from recycling the material
  - Recycled concrete is down-cycled
  - Re-use is uncertain
    - Accurate records available?
    - How much degradation?
Motivation to Improve Deep Foundations

• Cement is a major greenhouse gas (GHG) emitter
  – Estimates are 3-6% of worldwide GHG
  – Valuable natural resource

• Urban environments limit the type of deep foundation (White and Deeks, 2007)
  – Need low noise and impact to other buildings
  – Solution: Drilled and cast concrete piles

• Concrete piles
  – Good: Well understood and reliable, Versatile
  – Bad: Uses cement, Low tensile strength, spoil material
  – Circular Economy: High energy to remove
Existing Alternatives

- Geopolymers (Nazari and Sanjayan, 2015)
  - Direct Concrete Replacement alternative
  - Creates cement out of waste products (slags)
  - Low embodied energy
  - Less energy is lost to the ground
  - Circular Economy: High energy to remove; materials could be used elsewhere

- Recycled Steel Jacked-In Piles (White & Deeks, 2007)
  - Uses recycled steel to reduce embodied energy
  - Jacking eliminates noise pollution and structural interaction
  - Restrictions on soil conditions: no gravel or dense sand
  - More practical method to remove for reuse or recycling
  - Circular Economy: Easier to remove; materials could be used elsewhere
Existing Alternatives Cont’d

Timber Piles (Reynolds and Bates, 2009)

- Renewable resource: need sustainable forestry techniques
- Resilient in saturated conditions
- Treated in unsaturated conditions
- Most cost efficient pile type
- Excellent in ductility (earthquake loads)
- Design and analysis procedures established
- Circular Economy: Timber is lost to economy but is renewable

http://whc.unesco.org/en/list/1363

Future Alternative - Biogeotechnics

- **Microbial-Induced Carbonate Precipitation (MICP)**
  - Bio-mediated: Microbes enable cementation of soil
  - Soil type limited to sand
  - Bio-augmentation done on a large scale
  - Currently researching bio-stimulation in situ
  - May allow use of shallow foundations
  - Circular Economy: Solution inputs are lost to environment, but less valuable?

- **Enzyme-Induced Carbonate Precipitation (EICP)**
  - Bio-based: Enzyme enables cementation of soil
  - More soil types: Finer sand, maybe silt
  - Currently researching alternative source of enzyme
  - May replace deep foundation or allow use of shallow foundation
  - Circular Economy: Solution inputs are lost to environment, but less valuable?
Alternatives Enabling Reduction of Inputs

• Simulate Tree Root Systems
  – Highly efficient root systems, e.g., olive trees
  – Allow for reduction of materials

• 3D Printing Foundations
  – Use finite element and topology to create unique shapes and reduce material quantities
  – Could we have an 80% reduction of foundation material?
How can we get to the circular economy in this case?

- **Toolbox Approach**
  - Geography is key
  - Must look at each geologic situation differently

- **Policy/Incentives**
  - Example: LEED provides little credit for using sustainable foundations; no consideration from the circular economy perspective

- **Barriers to Entry**
  - Focus on cost only for foundation decision
  - Engineers are not familiar with new technologies
  - Incremental innovation is not rewarded on a major project
  - Patents: Do they help or hurt adoption of new technology?
References


