ENGINEERING SOLUTIONS FOR SUSTAINABILITY:
MATERIALS AND RESOURCES 3

Toward a Circular Economy

February 18–19, 2017 | Denver, Colorado

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Session 7: System Implementation

Alternative Deep Foundations to Enhance Sustainability of Infrastructure Projects

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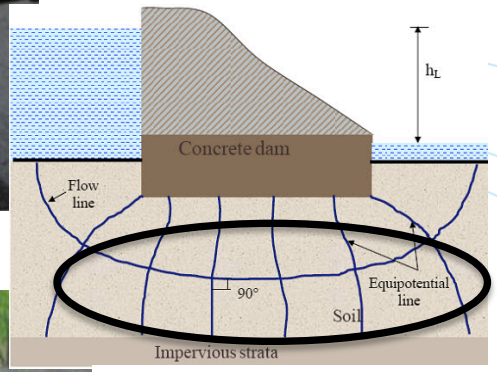
Outline

- 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)

https://www.environment.fhwa.dot.gov/



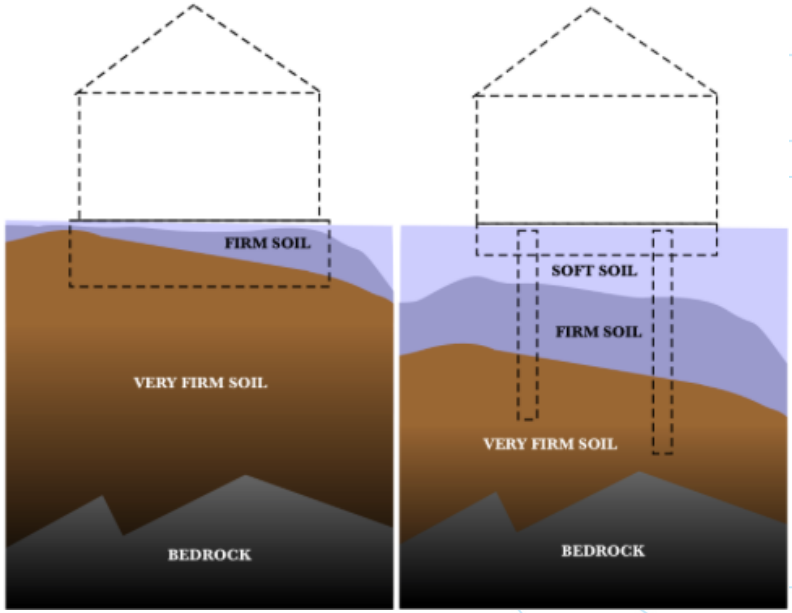
http://ecoursesonline.iasri.res.in/

http://www.wifrontdoorhousing.org/tag/building-foundations/

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

Shallow vs Deep



http://avalonstructural.com/NewDeepFoundations.html

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

Building Element	Volume cubic yards	% of Total Concrete
Superstructure		
Floor Slabs	509	4%
Walls and Columns	2,336	20%
Joist and Beams	8,298	70%
Foundation		
Drilled Piers	657	6%
Total	**11,800**	100%

Roughly 5-7% of concrete in building is used for foundation construction.

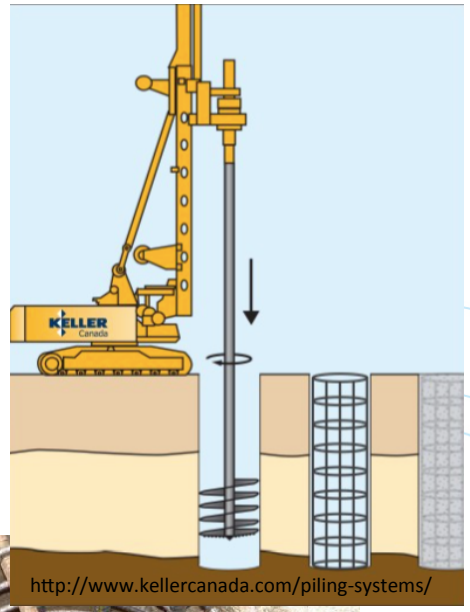
Material Reuse and Recovery – Office Building in Austin, TX

- 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



http://www.kellercanada.com/piling-systems/


http://studyblue.com

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

Deeks, White, and Bolton (2005)

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

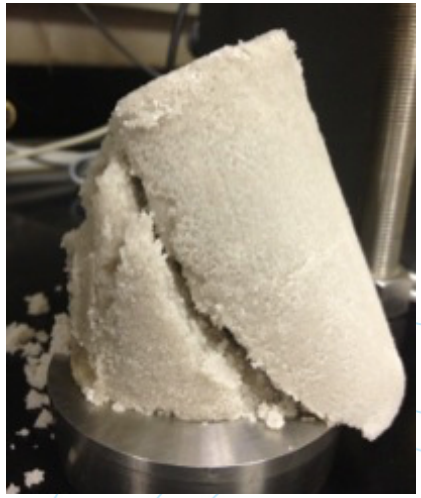
http://whc.unesco.org/en/list/1363

http://www.woodworks.org/wp-content/uploads/Rollins-Timber-Piling.pdf

Reynolds and Bates (2009)

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?



http://www4.ncsu.edu/~bmmorten/page1/page1.html

- 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?

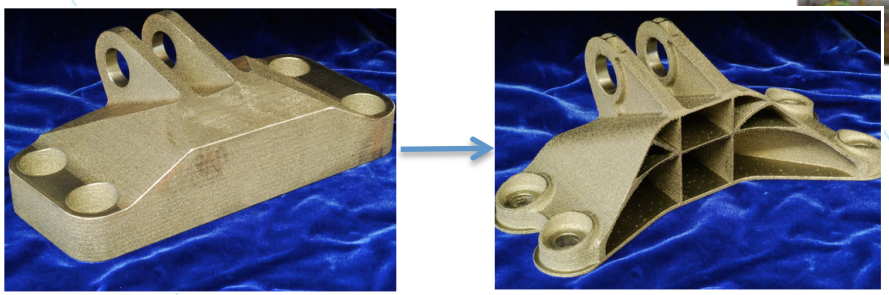
van Paassen,et al., 2009

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?

Dejong, 2015



http://www.gereports.com/post/77131235083/jet-engine-bracket-from-indonesia-wins-3d-printing/

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?

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