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and

Overview of Sustainable Ground Improvement Systems

May 22, 2024 / 10:15 AM – 10:45 AM

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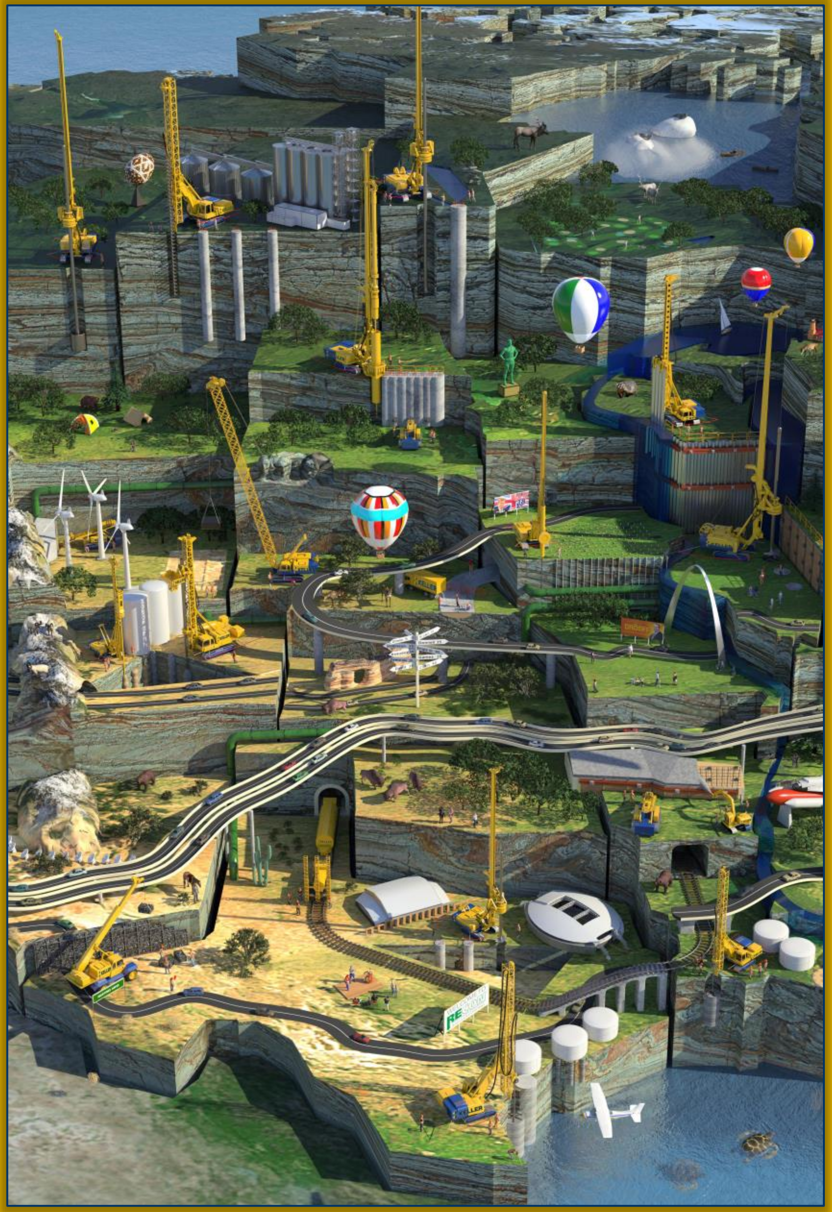
Agenda



Keller's 'Four Ps' of sustainability

Planet

We are helping to build a sustainable future by using less resources, reducing carbon emissions and reducing waste across our operations, whilst playing a positive role in our local communities, the environment and wider society.

People

We operate in a way that respects people and their health, safety and environment, always striving for zero harm. Our motivating and inclusive culture makes us a good employer that people are proud to work for.

Principles

An effective framework of systems and controls ensures we manage risk and run our company well, and we seek out partners who understand our principles and the standards we operate by.

Profitable projects

We continually innovate to support more environmentally sustainable construction, actively transforming our product portfolio to help our customers use fewer resources, reduce their carbon emissions and improve their environmental impact. Making sustainability core to our business helps differentiate us from our competitors and helps us achieve long-term profitability and growth.

Pillars of Sustainability

Environmental Sustainability	**Reduced resource consumption** (materials, water, energy) **Lower carbon footprint** (equipment, transportation, emissions) Use of **Sustainable materials** (recycled material)
Social Sustainability	**Safety** (zero harm to workers and public) Employee well-being (**positive and inclusive work environment**) **Community engagement** (open communication, public involvement, **minimized disruption, improving local infrastructure**, partnering with local businesses)
Responsible Practices	**Ethical sourcing** (**responsible material procurement**, adhering to regulations) **Transparency** and open communication with stakeholders **Innovation (researching sustainable techniques and materials)**
Economic Profitability	**Sustainable solutions can lead to profitability (efficiency, resource conservation)** **A profitable company can invest in sustainable technologies** **Profits can be used to fund research and development of new sustainable solutions** **Durable foundations ensure long-lasting structures, minimizing future repairs and environmental impact**

Geotechnical Construction Techniques

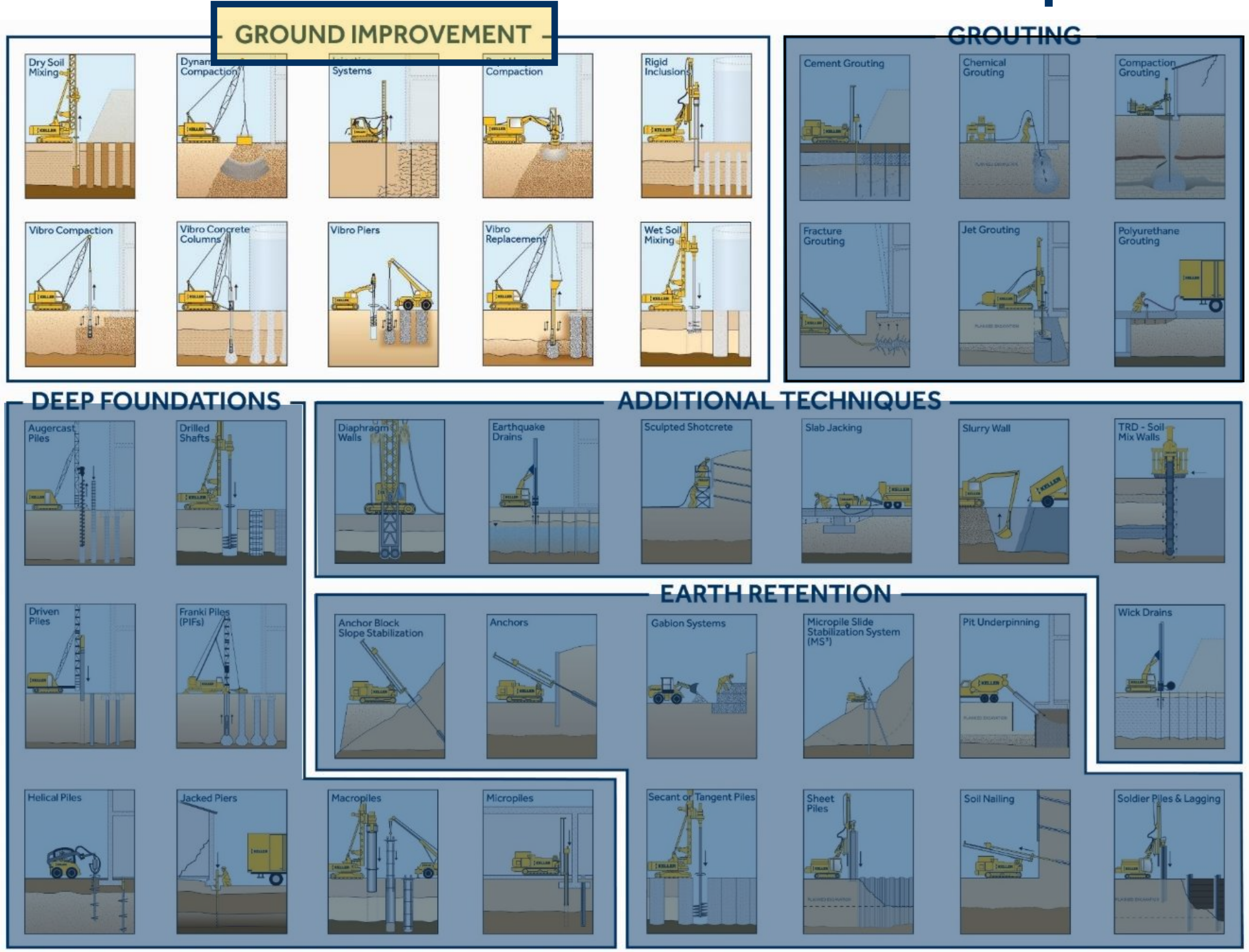
Optimal solutions considering:

Soil

Cost

Schedule

Risk



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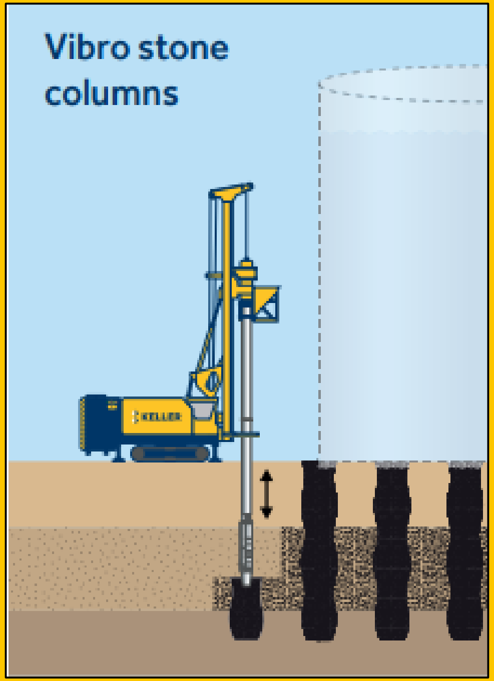
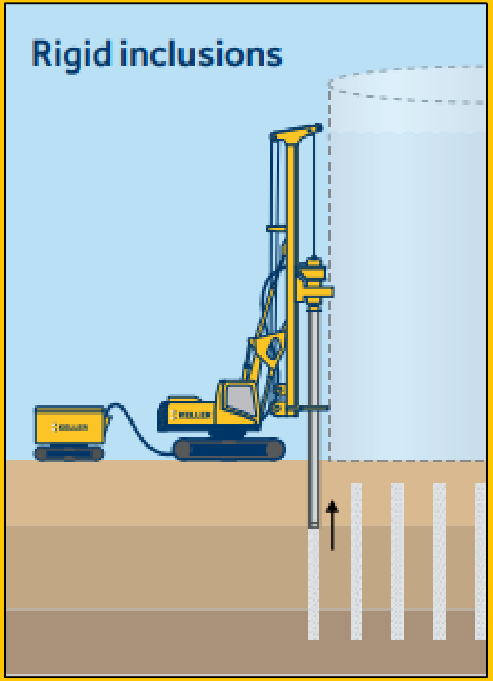
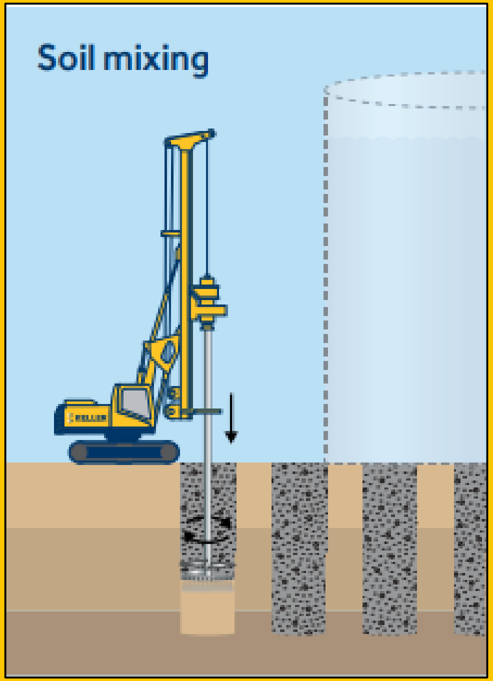
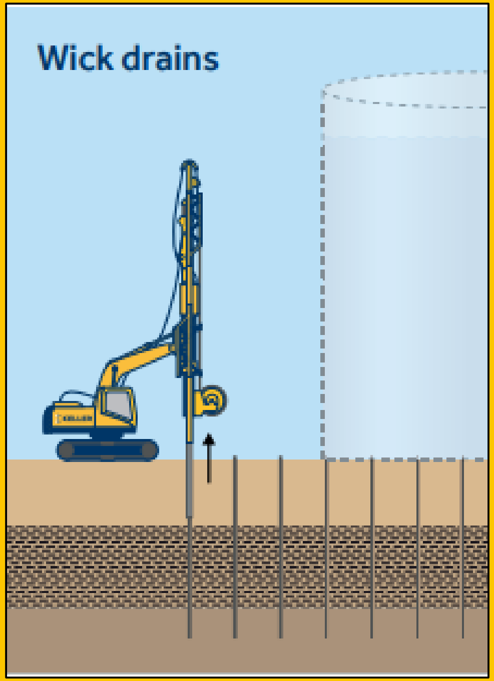
Ground Improvement Techniques

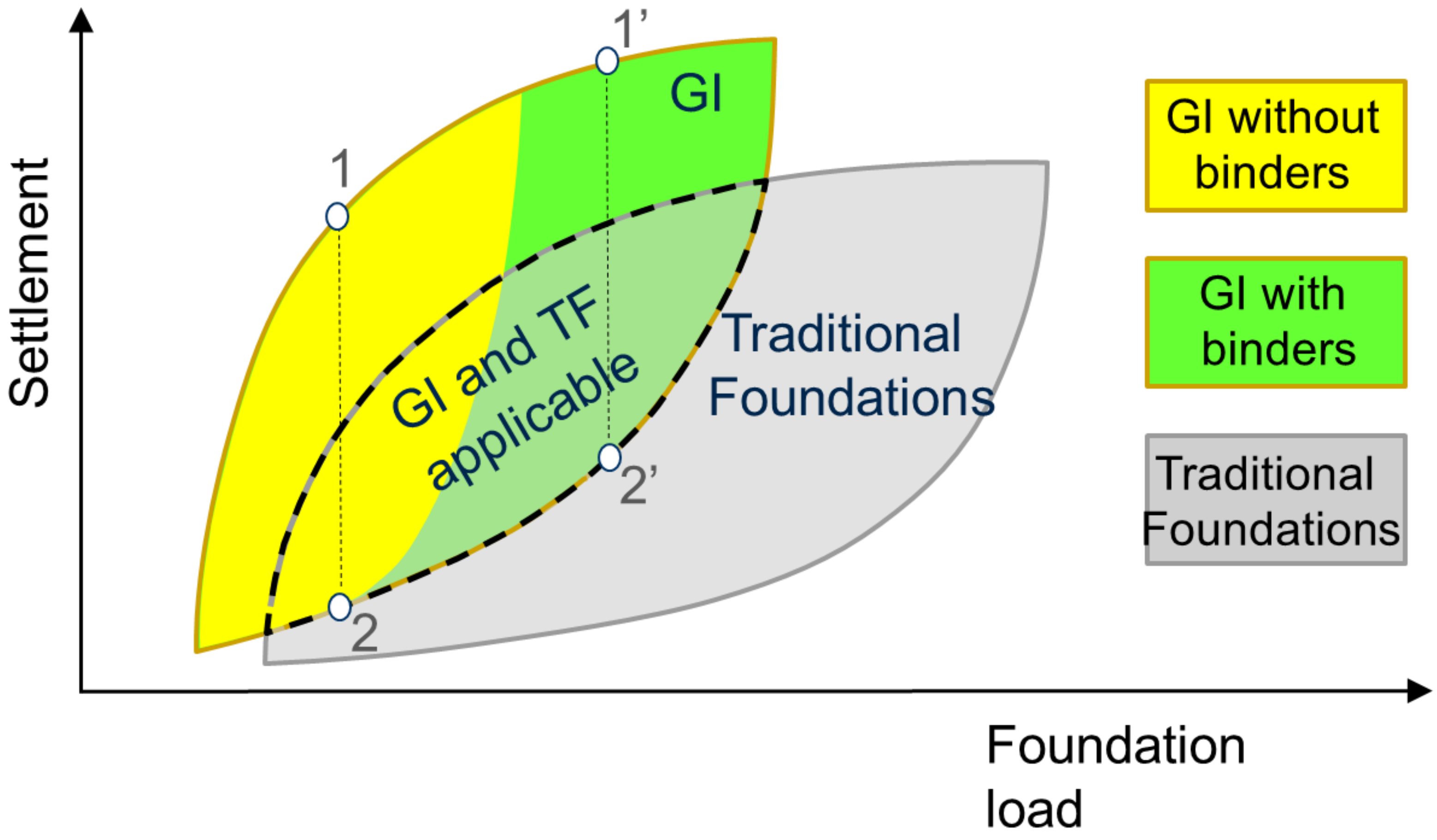








How Do We Select The Appropriate Solution?



Aggregate Piers

- Aggregate piers are constructed by drilling a hole and filling it with crushed stone in lifts. The stone is compacted at each lift using a down-hole vibrator to densify the aggregate fill and surrounding soils.

- Often used to **increase bearing capacity** of native soils and **reduce potential settlement** below shallow foundations (spread footings)

Identifying Suitable Projects

- Allowable bearing pressures from 3 – 8 KSF
- Locations with deep rock / bearing formation and sandy or stiff clays above
- Sites free of organics and deep, soft clays
- Mitigate liquefaction or lateral spreading
- Planned structures that can tolerate some settlement
- Can be used in conjunction with moisture conditioning and water injection to stabilize expansive clays

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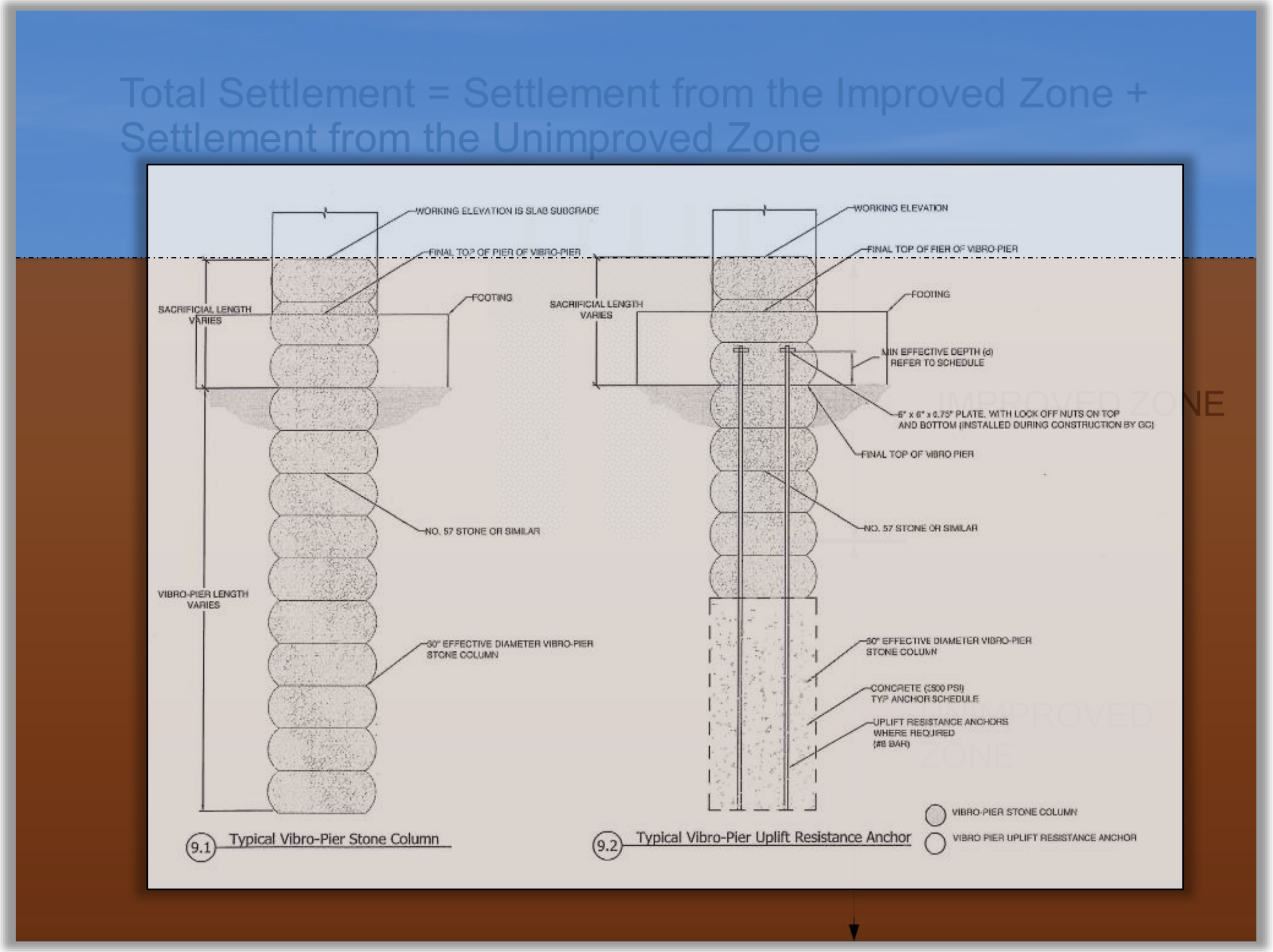
Aggregate Piers



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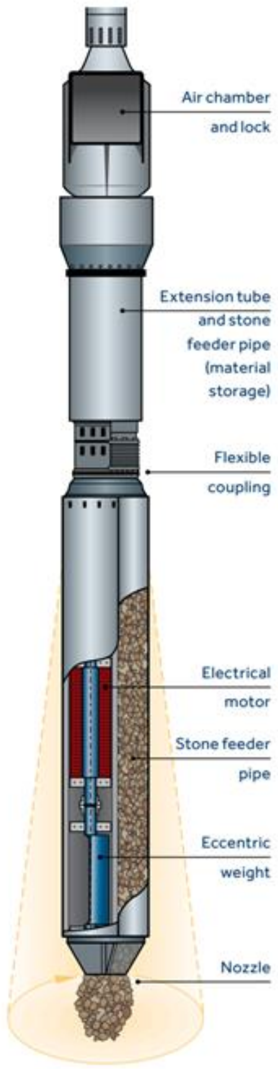
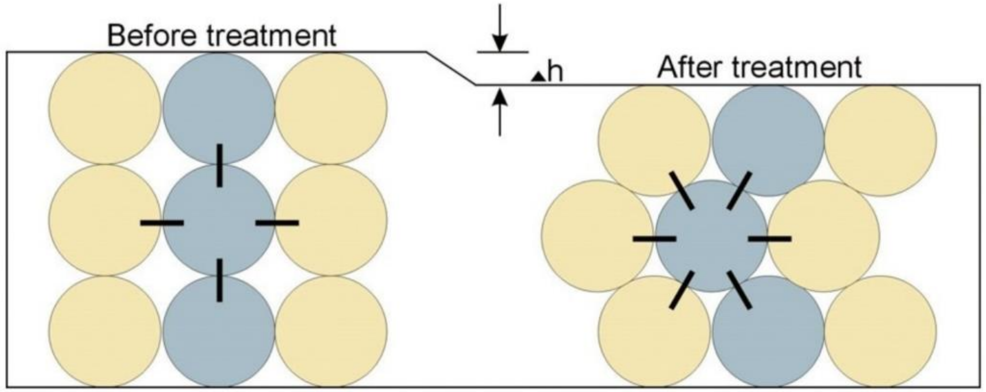
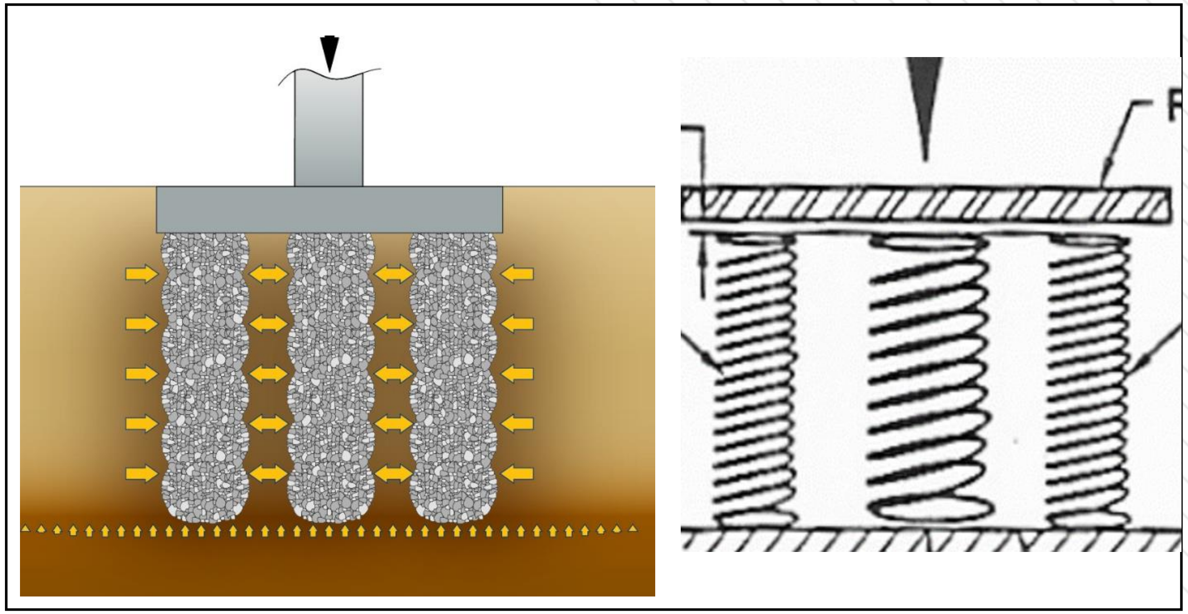
Vibro Piers/Vibro Compaction







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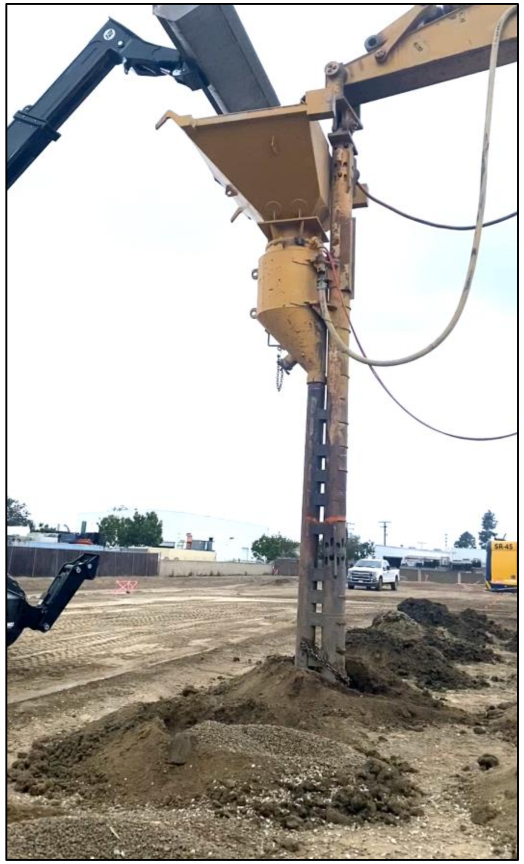
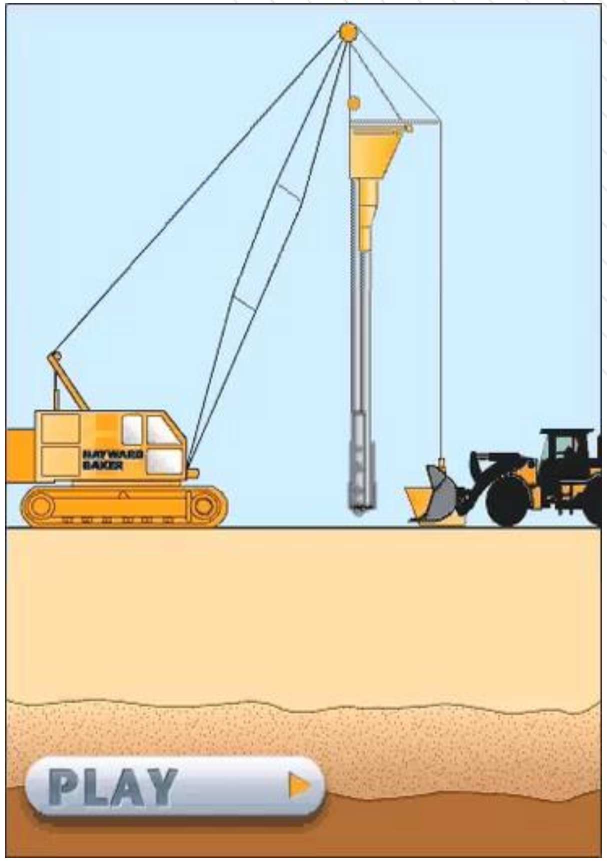
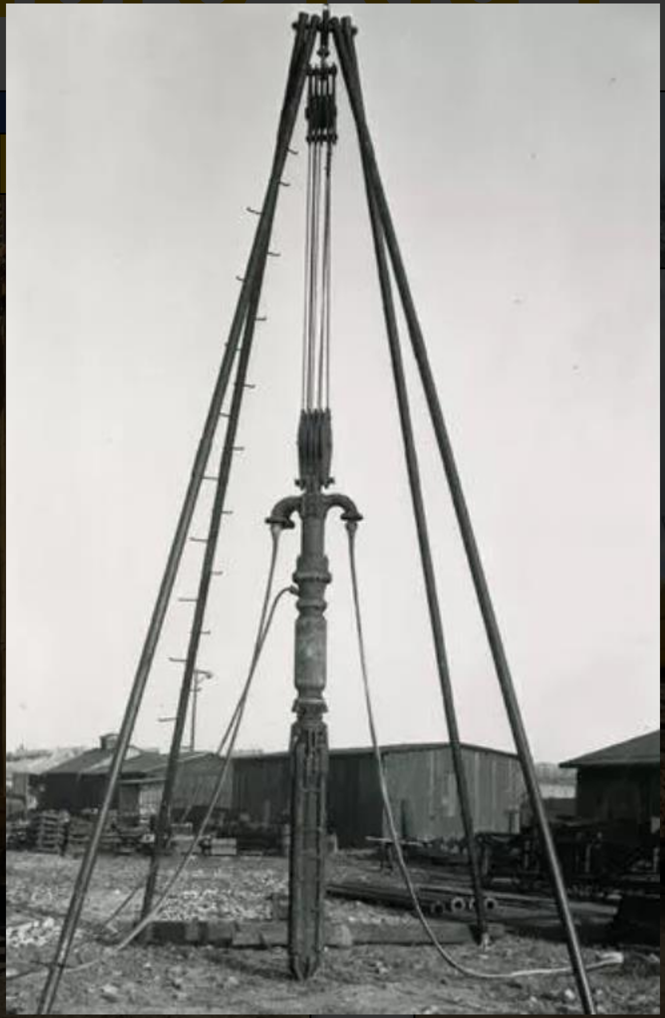
Installation Methods

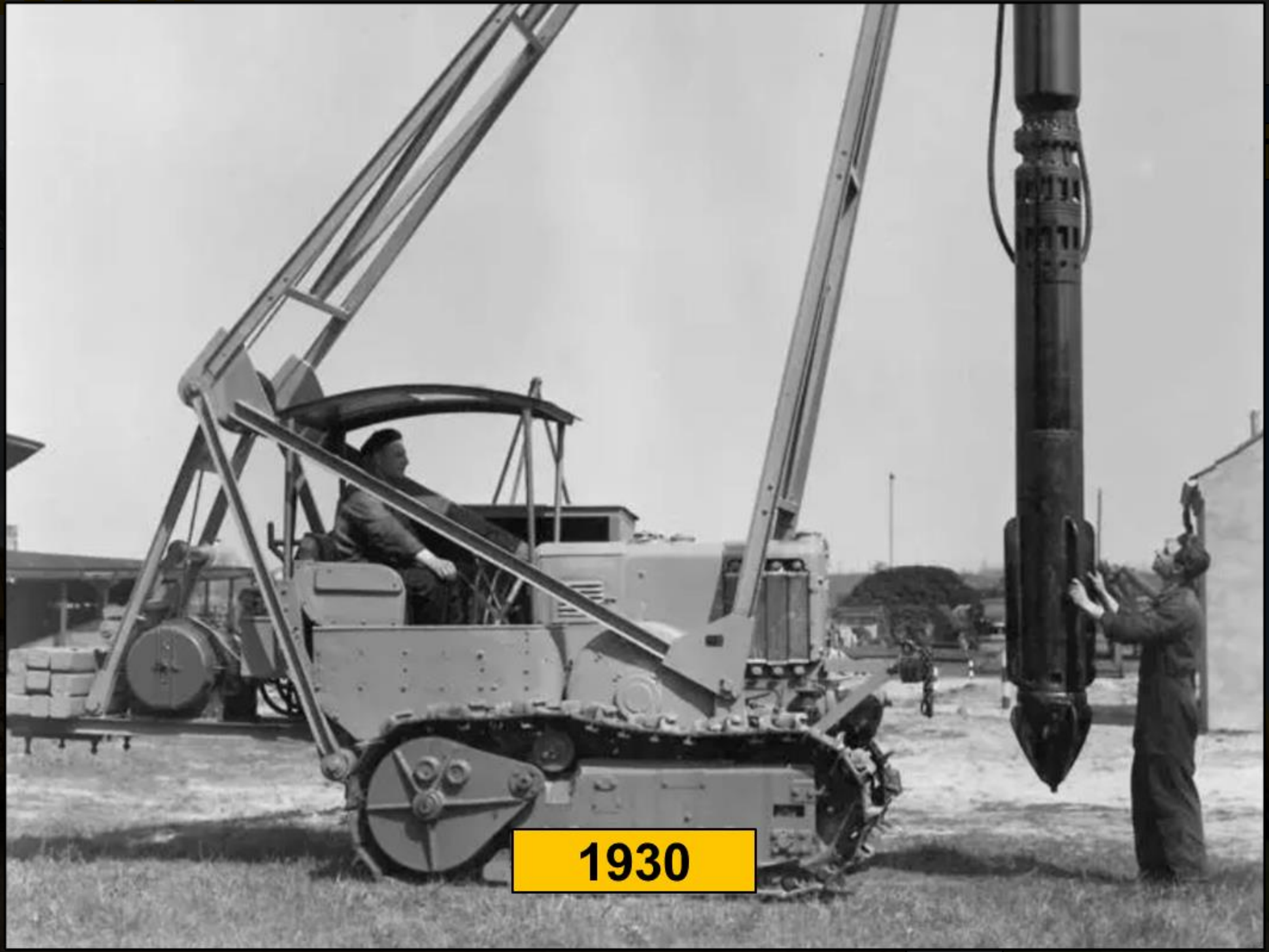




Bottom Feed – Caving Soils   Top Feed – Cohesive Soils

Vibro Rig Fleet





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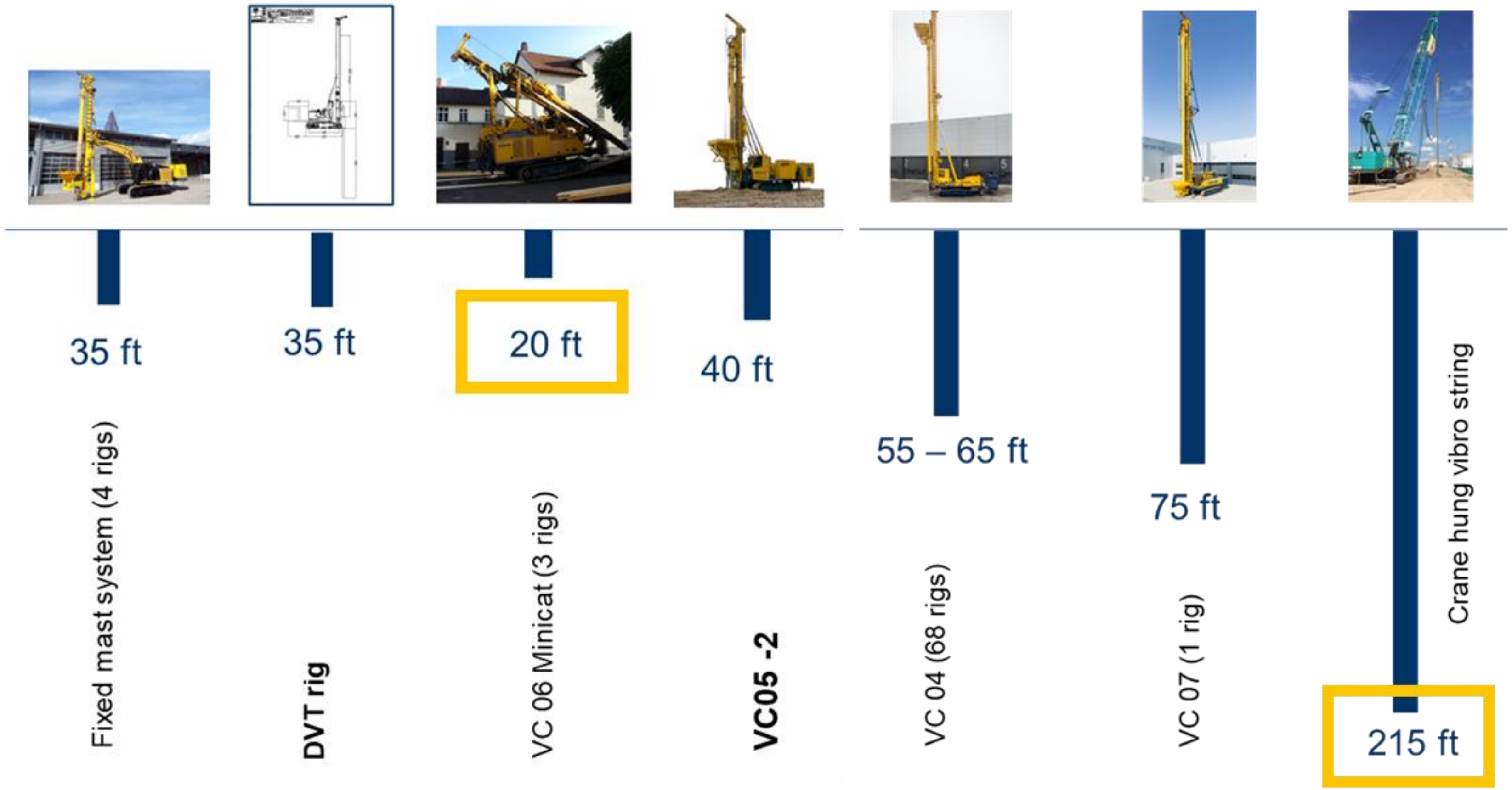
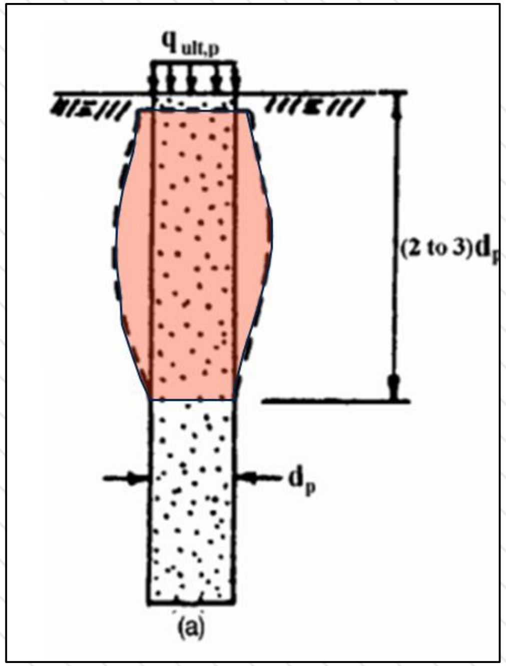
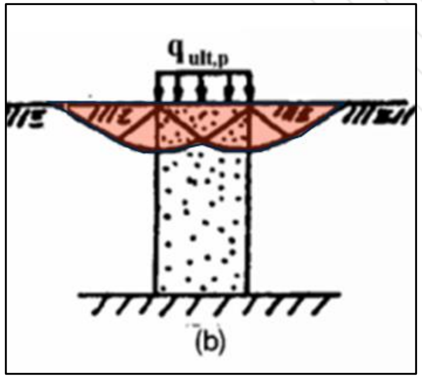
Vibro Rig Fleet

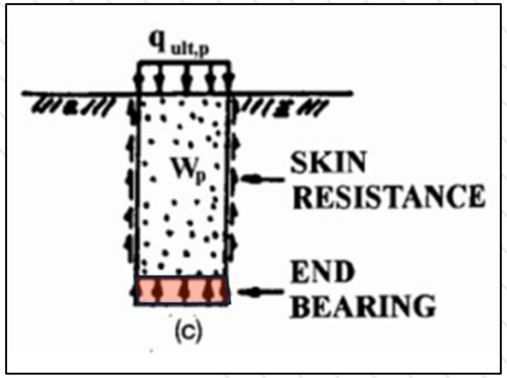


Limitations of Aggregate Piers

- Deep soft clay within stress influence zone
- Variable depth to a competent soil/rock layer
- Thick (5’+) deposits of very soft clay
- Profiles with significant amounts of organics or decomposable materials (e.g., landfills) >2’ – 3’ thick
- Bearing Pressures >8 KSF
- High columns loads >2,300 kips
- Excess settlement from adjacent footing stresses
- Tight differential settlement tolerances







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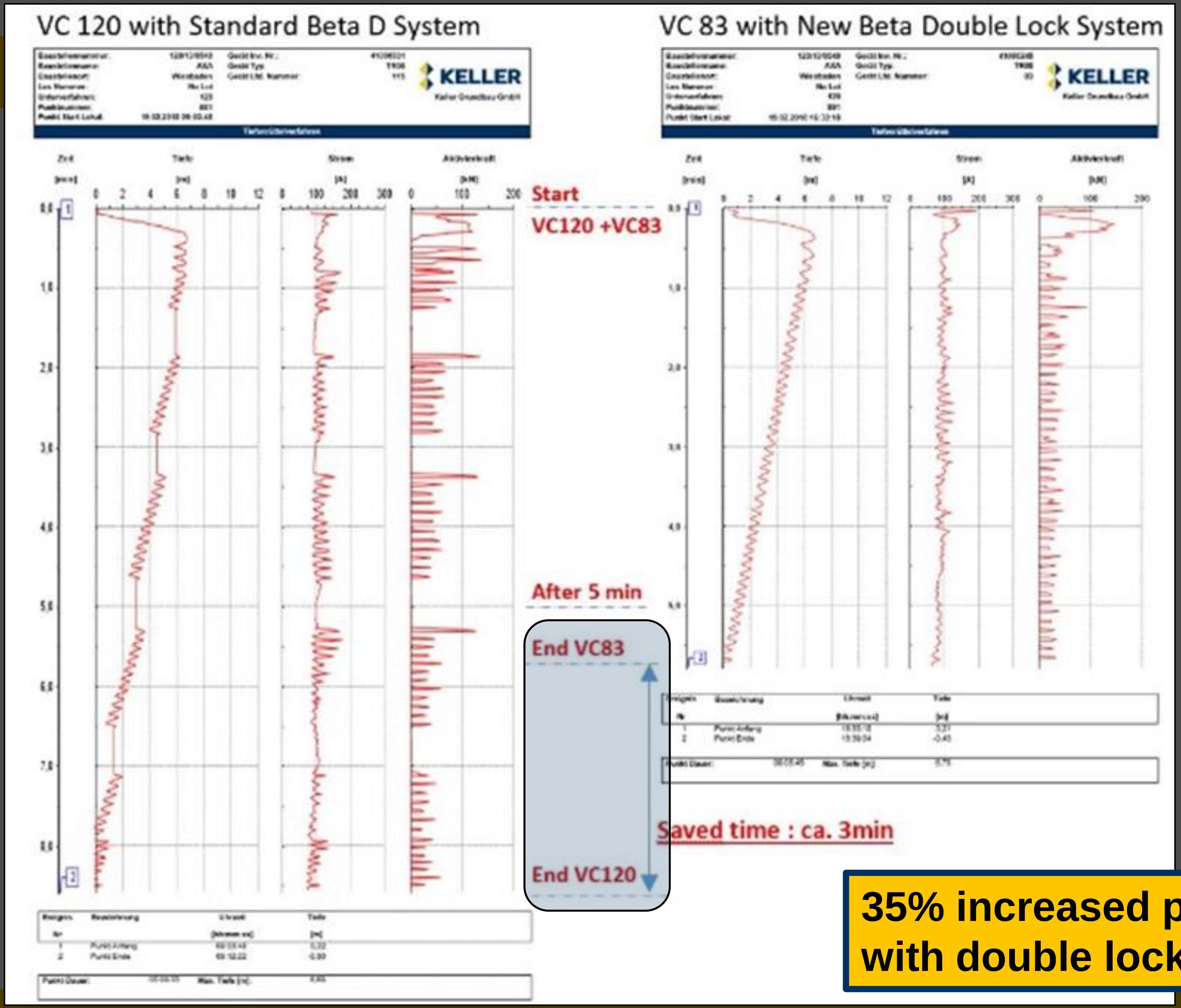
Efficient Production Rate

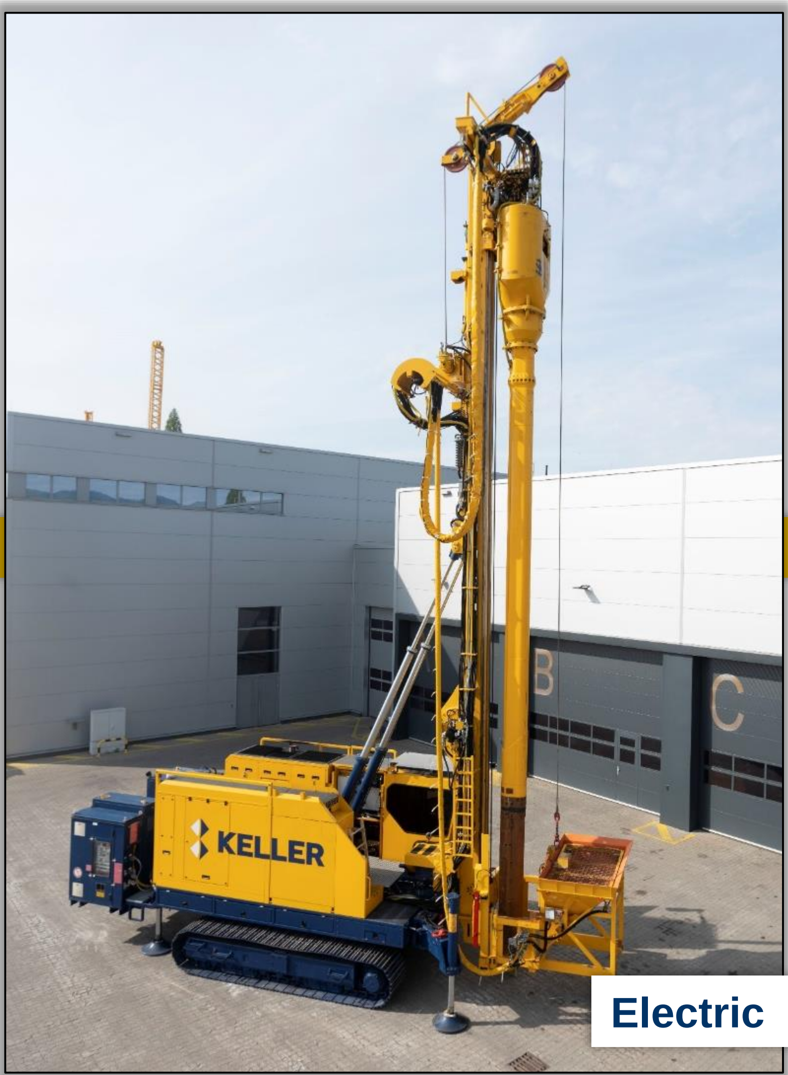
Double Lock Bottom Feed System = Optimized Production

Efficient



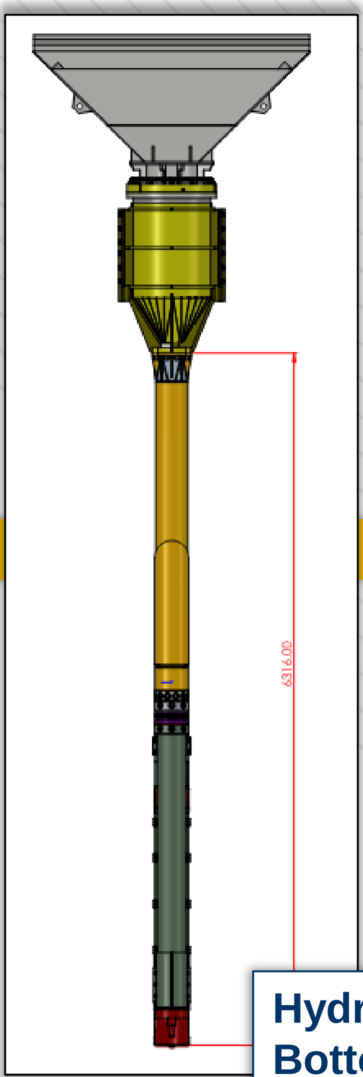
35% increased production rate with double lock system

Hydraulic Vibrators



Electric

Hydraulic Top Feed



Hydraulic Bottom Feed

Reduced Emissions: Eliminates need for separate diesel generator

Energy Efficiency: Leverages existing excavator hydraulic system

Simplified Operation: No genset or variable switch box. Small footprint and cheaper freight.

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No Foundation to Vibro Piers

1600 tons CO_2e + Waste reduction

Reducing footing sizes using Vibro Piers & Recycled Concrete Aggregate

VALUE ENGINEERING

Bearing Pressure Increase
Footing Size Decrease = 38,500 ft^2

SAVINGS

Concrete = 4,200 yd^3
Steel = 251 tons
Reduced costs

13 CLIMATE ACTION

Reduced emissions by
1,600 tCO_2e

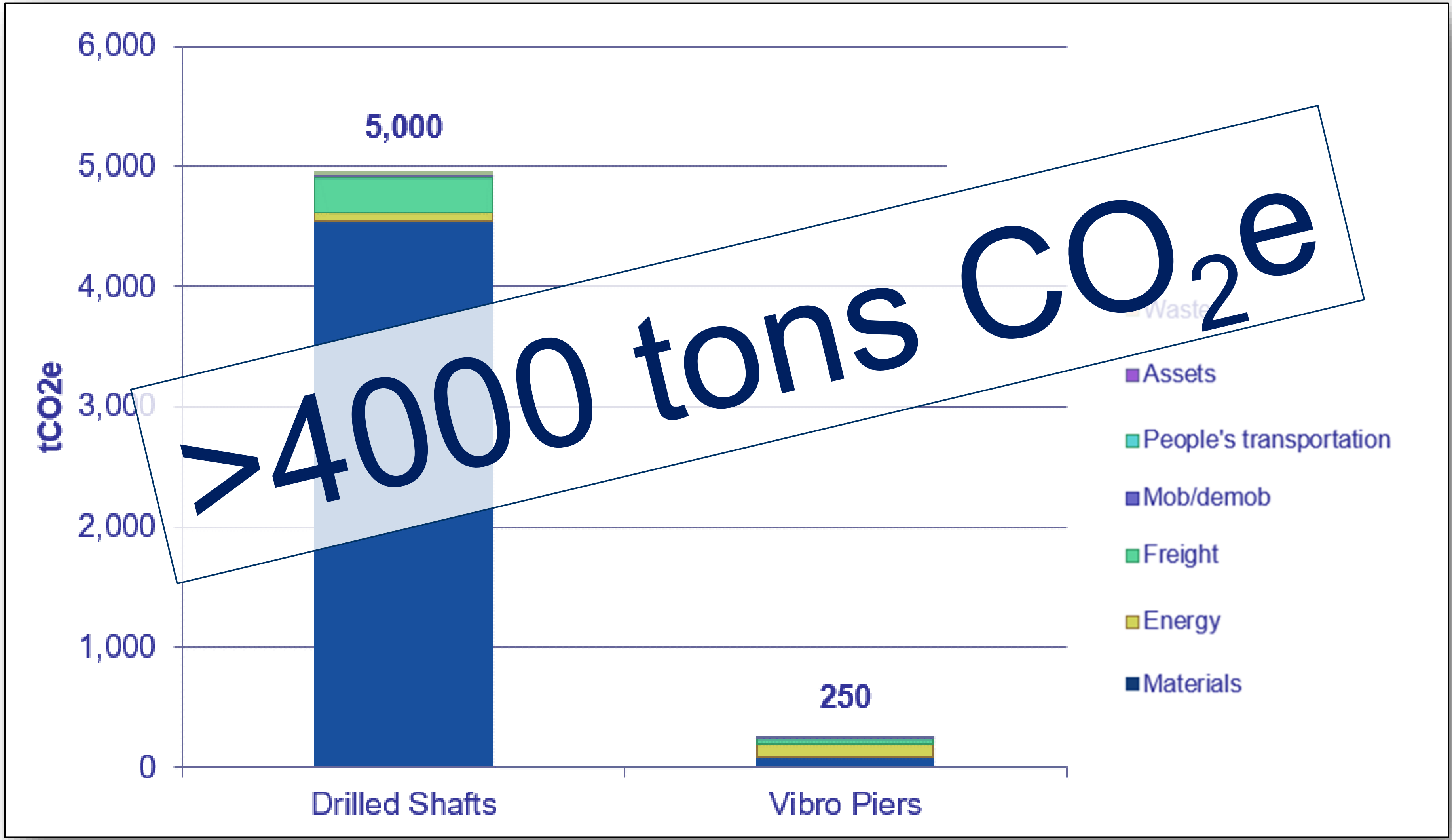
Equivalent to emissions from
345 US cars running for a year

12 RESPONSIBLE CONSUMPTION AND PRODUCTION

Vibro Piers used
Recycled Concrete Aggregate

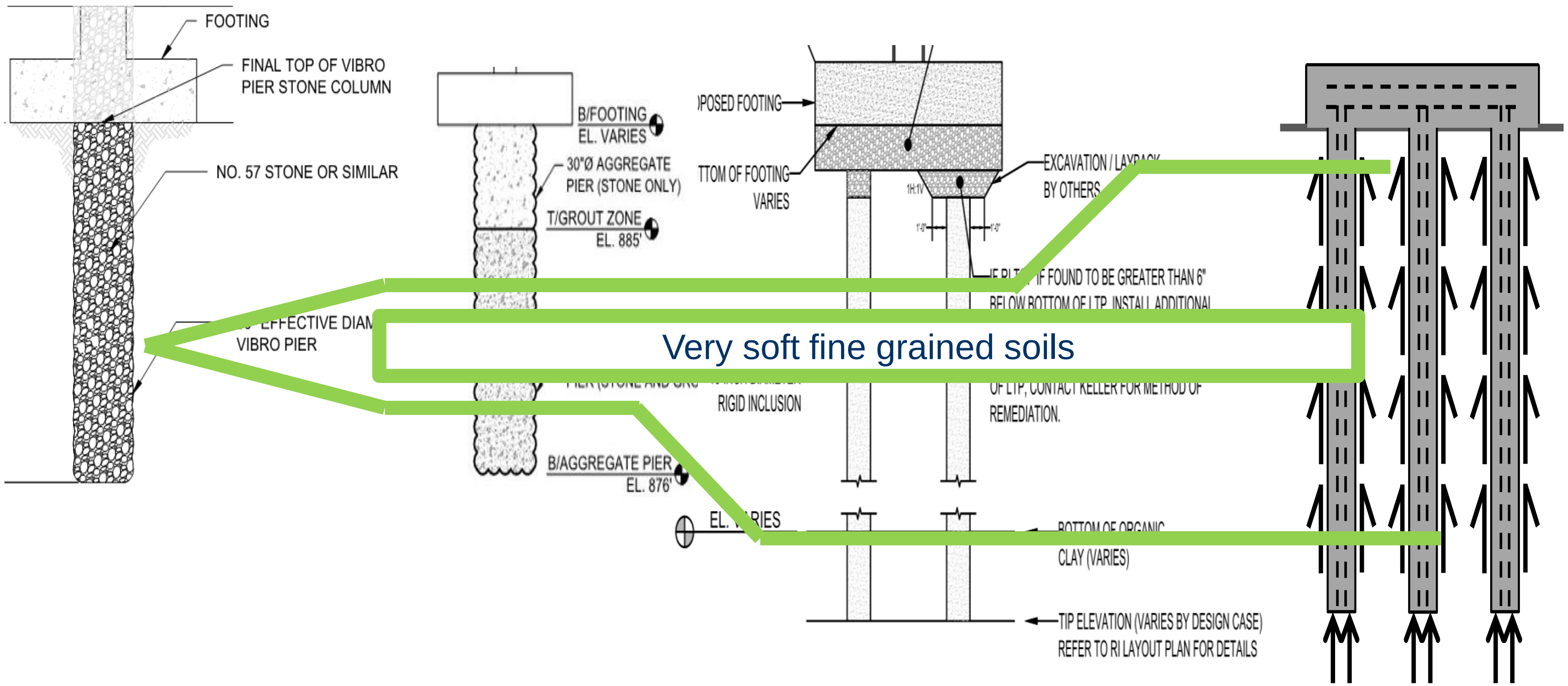
Landfill space saved is equivalent weight of garbage generated by **25,800 people** per year

Drilled Shafts to Vibro Piers



Why Rigid Inclusions? …"It's a Vibro job until it is not."

Aggregate Piers → Grouted Aggregate Piers → Rigid Inclusions → Deep Foundations



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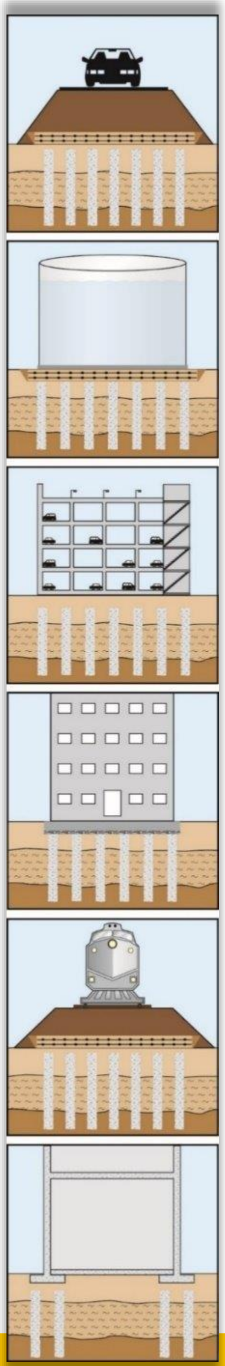
Rigid Inclusions

- High-modulus grout columns ranging from **12” to 18” in diameter** with **compressive strength from 2,500 PSI to 4,000 PSI**
- Slump: 6” +/-1” for **Vibrated Pipe Method** to 9” +/-1” for **Drilled Displacement Method.**
- Typical Depth of 20-60 feet
- Transfers 50% to 95% of the load
- Can reduce estimated settlement by a factor of 4 to 10
- Compressible soil
- Time (surcharge / wait isn’t an option)
- Tight settlement tolerances
- Vibrations or noise are an issue



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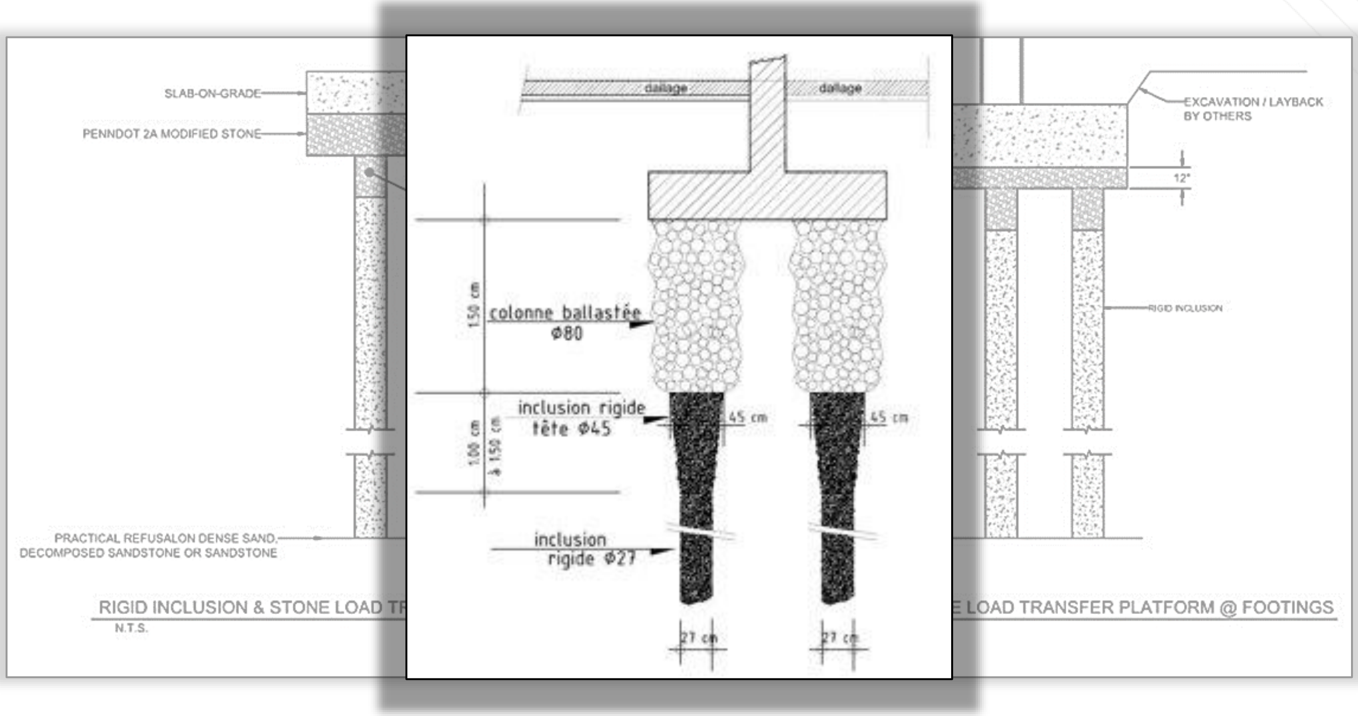
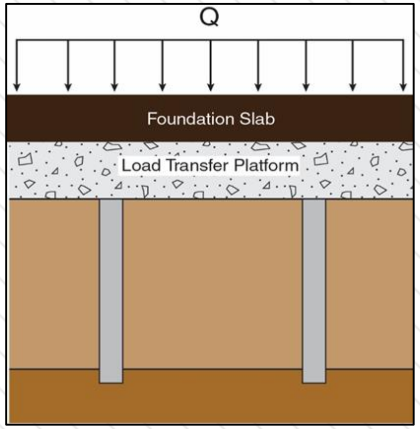
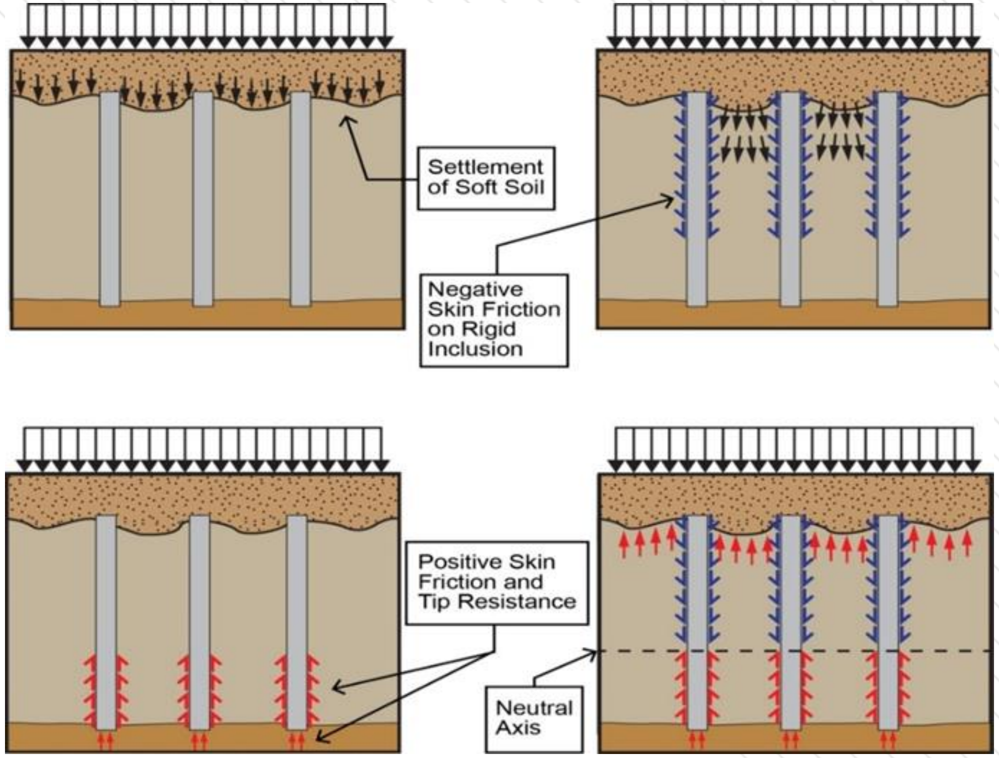
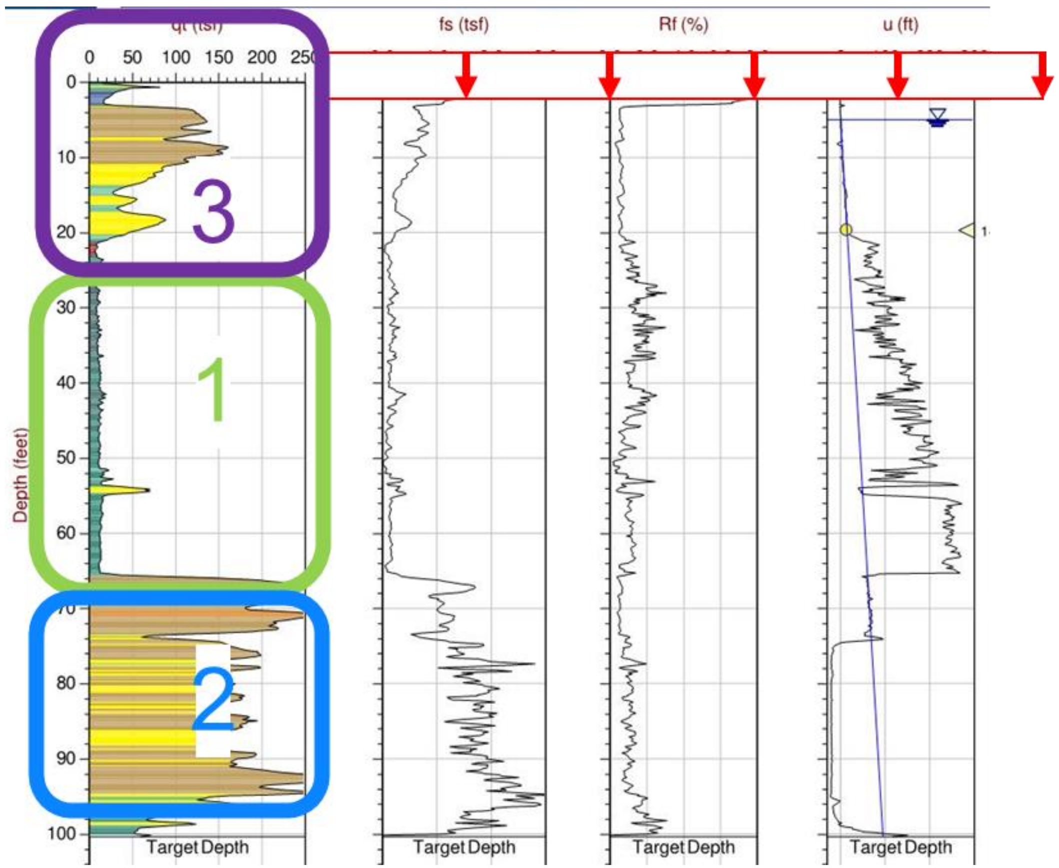
RI Load Transfer Pads





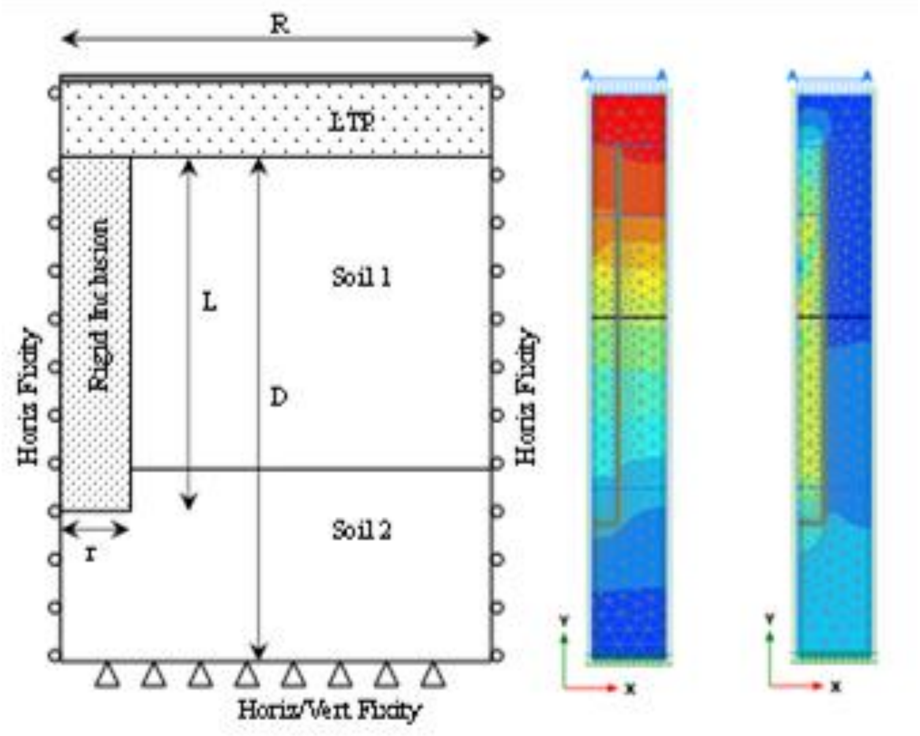


Design Optimization & Key Considerations



- RI design considers the behavior of a single inclusion within a grid, **utilizing FEM (axisymmetric unit cell)** to account for potential movements between the inclusion tip and soil, and the inclusion head and load transfer platform (LTP).
- Typical allowable RI loads (FS=1.5): 12" (40-100 kips), 14" (70-140 kips), 16" (100-200 kips), 18" (180-280 kips)

Design Optimization & Key Considerations



- **CPT and consolidation data** will often allow us to significantly increase the efficiency of the design and reduce cost
- Understanding the time rate of consolidation is crucial for many RI projects.
- **Grain size distribution and friction angles** influence design considerations

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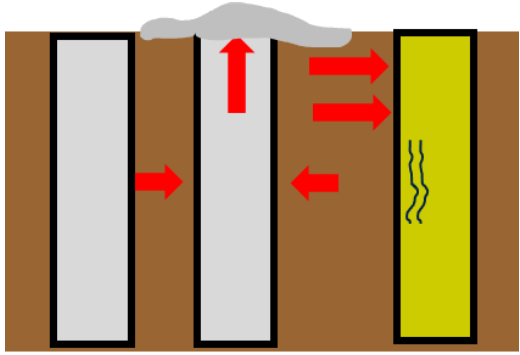
RIs Construction Considerations

- **Selecting readily available materials**
- **Monitor closely spaced RIs** for grout rise (necking)/cracking **from horizontal displacement.**
- **Maintain a minimum 3 to 4 D center-to-center spacing**.
- **If ARR > 5%, we need to be more considerate of installation sequence**



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Limitations of RIs

- **Remote areas where ready-mix is not readily available**
- **Groundwater** and/or very soft soils at or **near the bottom of footing elevation** (not good for ground improvement in general)
- Sites with **large groundwater gradient**
- Sites with **liquefaction or cyclic softening of clays**

RIs Drilling Tools

Full displacement auger (FDA)

Allows:
- **less spoil generation**

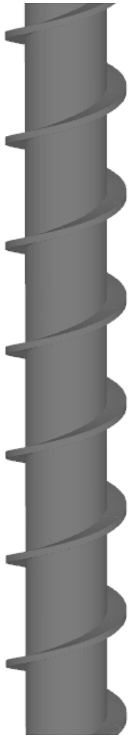
In return:
- **Less embedment capability** in dense/hard bearing soils
- More difficult to pass through thick hard/dense layers

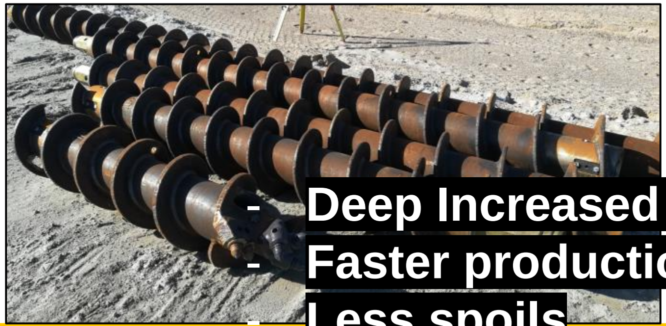
FDA + long starter

Allows:
- **deeper embedment** in dense/hard bearing soils
- aids in penetration in stiffer/denser layers

In return:
- **some spoil removal required**

Partial displacement (PDA)





- **Deep Increased bearing capacity**
- **Faster production rates**
- **Less spoils**

Continuous flight auger (CFA)

Allows:
- **deep embedment** capability in bearing soils
- helps the penetration work (less pull-down force required) through dense/stiff layers

In return:
- generally slower process
- **excess grout consumption**
- **large spoil removal required**
- Less soil displacement and ground improvement and therefore no increase in soil strength or soil-grout interface

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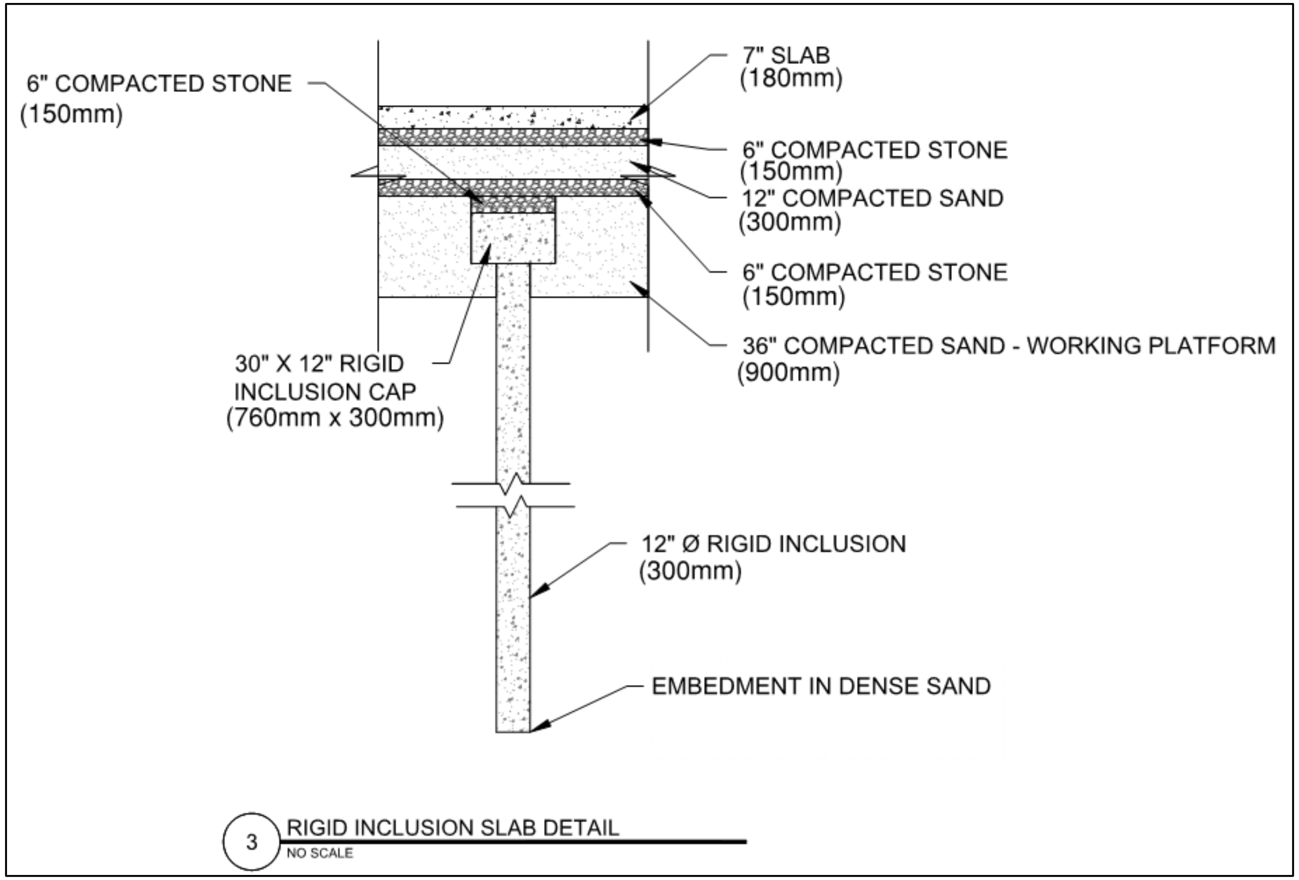
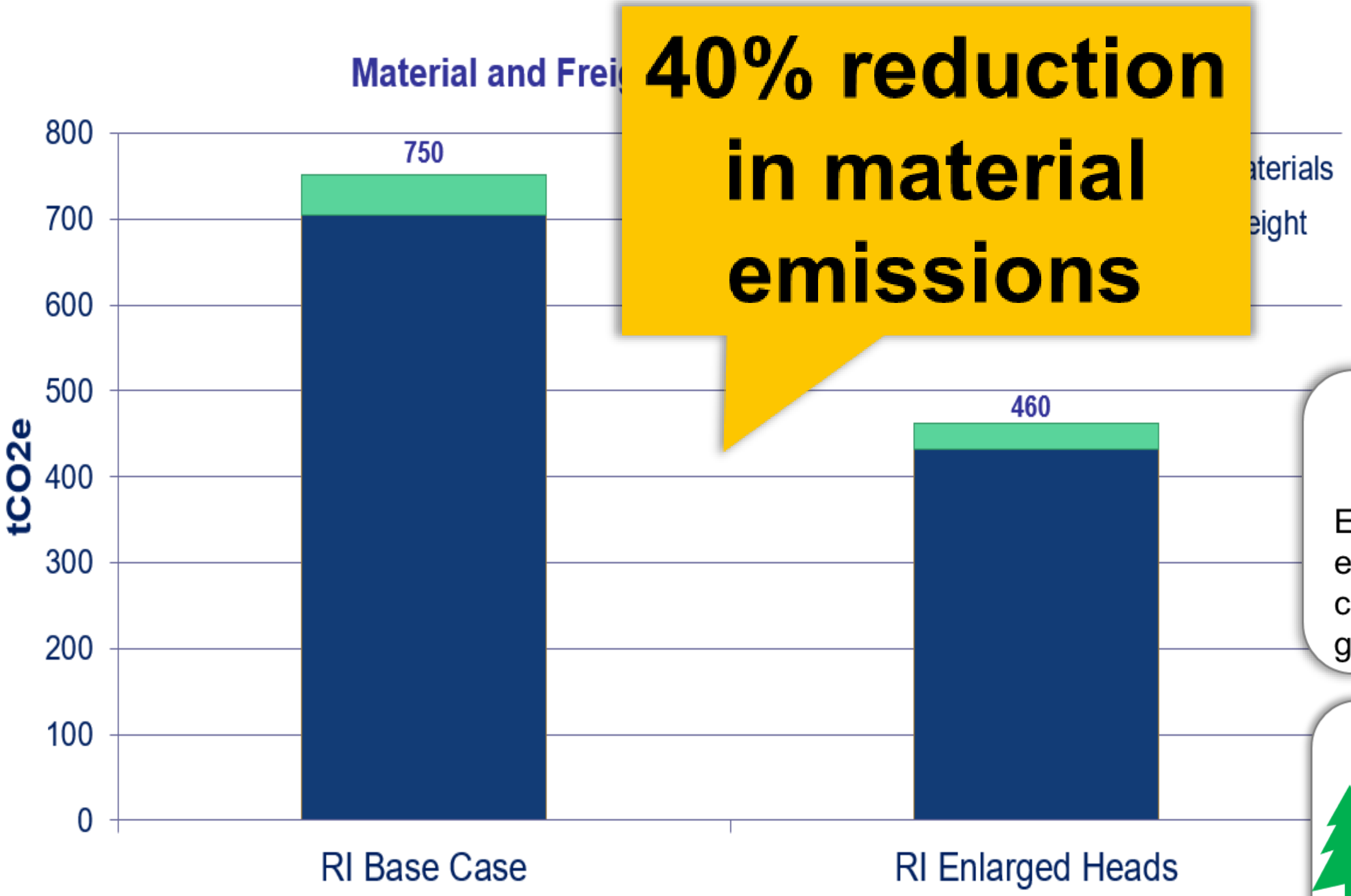
Efficient Design with RIs 'Enlarged Heads'



- **Increase area replacement ratio at interface between RI and LTP**
- Attract more load to top of RI
- **Increase spacing** between elements for large area loads
- **Total grout quantity is reduced** compared to design without "enlarged head"

Efficient Design with RIs ‘Enlarged Heads’



Equivalent emissions from consuming 26,000 gallons of diesel.

Amount of carbon sequestered by 311 acres of forest in one year

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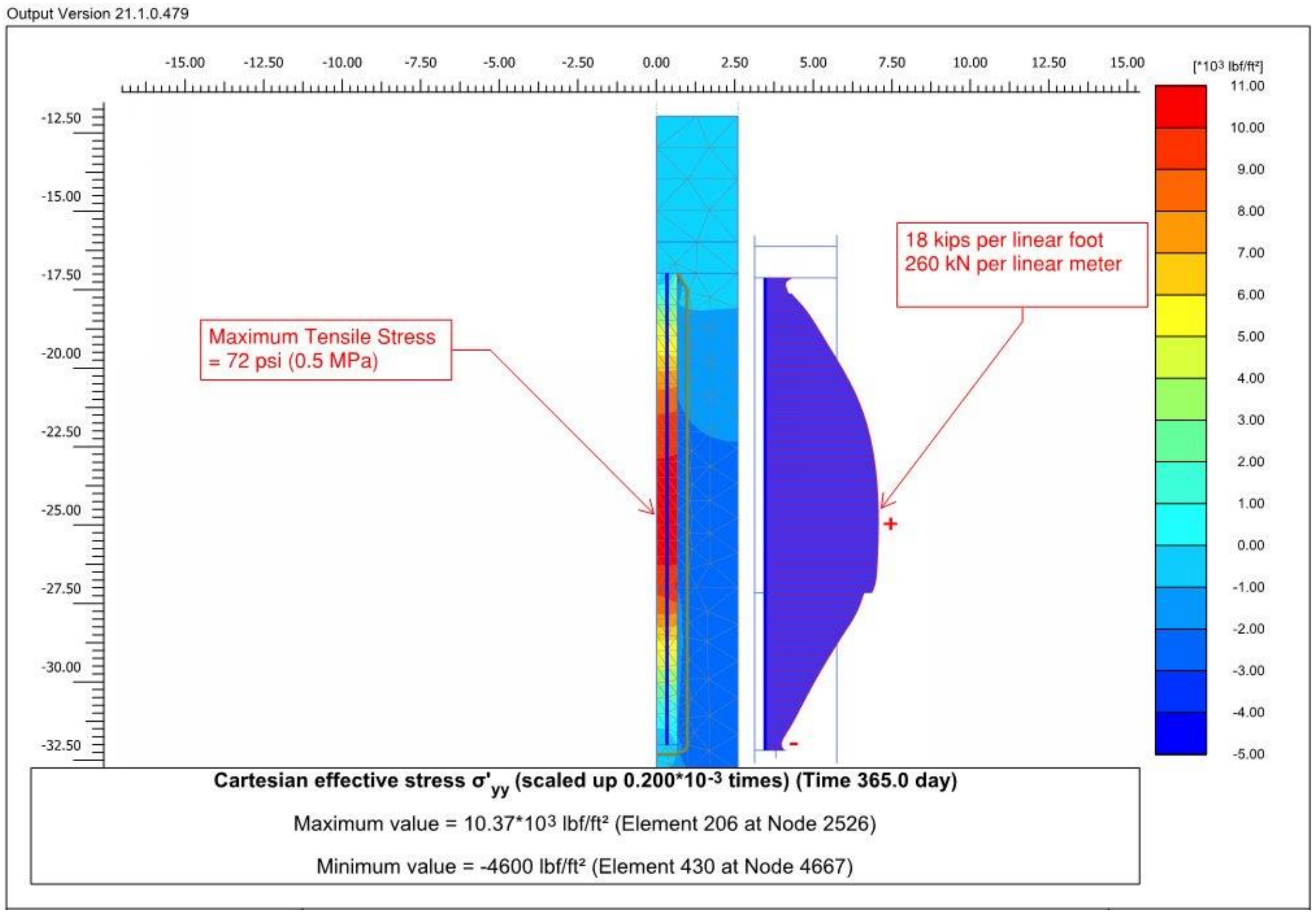
Polymer Fiber Reinforcement



- **Identify potential for tension in RI**: Lateral loads, Uplift/heave
- Steel reinforcement are commonly used to **prevent cracking and reduction or loss of structural capacity**
- **Polymer fibers can be used to replace steel reinforcement in some applications.**

Polymer Fiber Reinforcement

- Challenge:
  Possible tension in 500/6,000 elements
- Option 1: 500 steel #8 (1-inch) deformed bar with centralizers. **Estimated cost to install was approximately $30,000**
- Option 2: Add polymer fiber reinforcement to concrete/grout at **4 lb/CY. Estimated cost to install was approximately $30,000**

- Keller chose option 2 – Polymer fiber reinforcement
  - Carbon reduction was about **33-tons over the 500 elements**
  - No loss of productivity or additional manpower

Equivalent emissions from driving a car **74,000 miles**!

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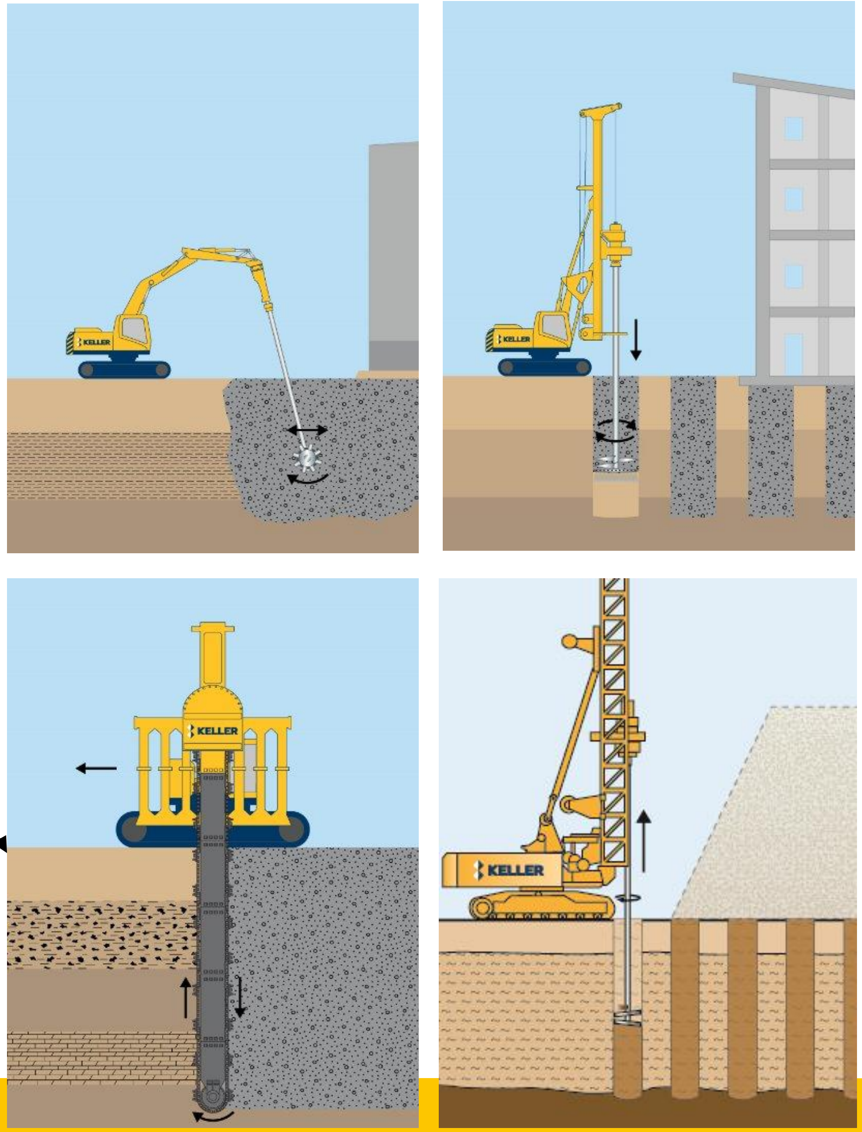
Soil Mixing

- A method to blend in-situ soils with a cementitious binder to improve problematic soils: Wet Mixing, Dry Mixing – aka, mass mixing (WC > 60%),
- Can also be used for liquefaction mitigation
- Tools can range from 3 ft to 8 ft in diameter.
- Unconfined compressive strength typically ranging from 50psi to 300psi
- Depths of 80 – 90 feet possible

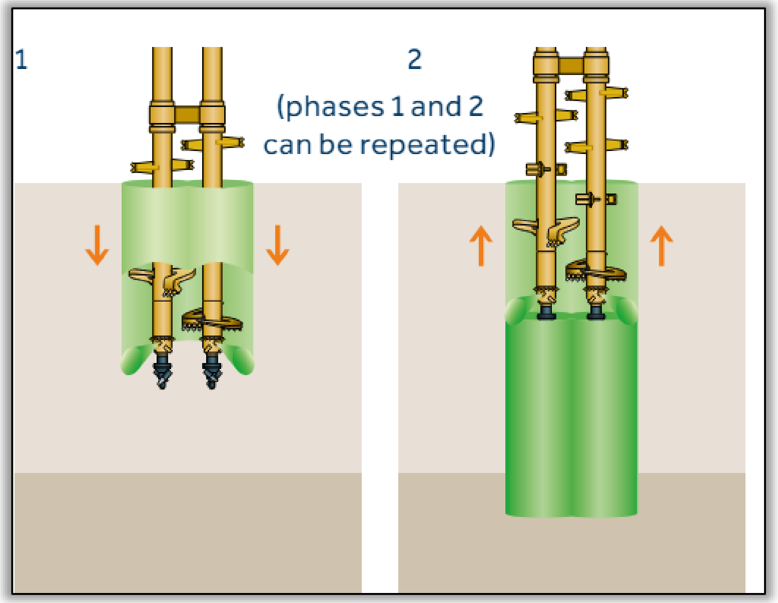
Soil Mixing Application

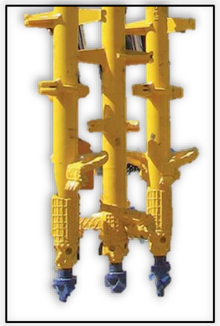
- Soil Mixing is ideal for soft materials that can be "easily" penetrated and treated with cementitious binder.
- Ideal method for reducing settlement of compressible / weak (organic) cohesive soils and loose granular soils
- Trench cutting and remixing deep (TRD) for use in installation of **soil mix walls** in stiffer profiles **for earth retention and groundwater control**.

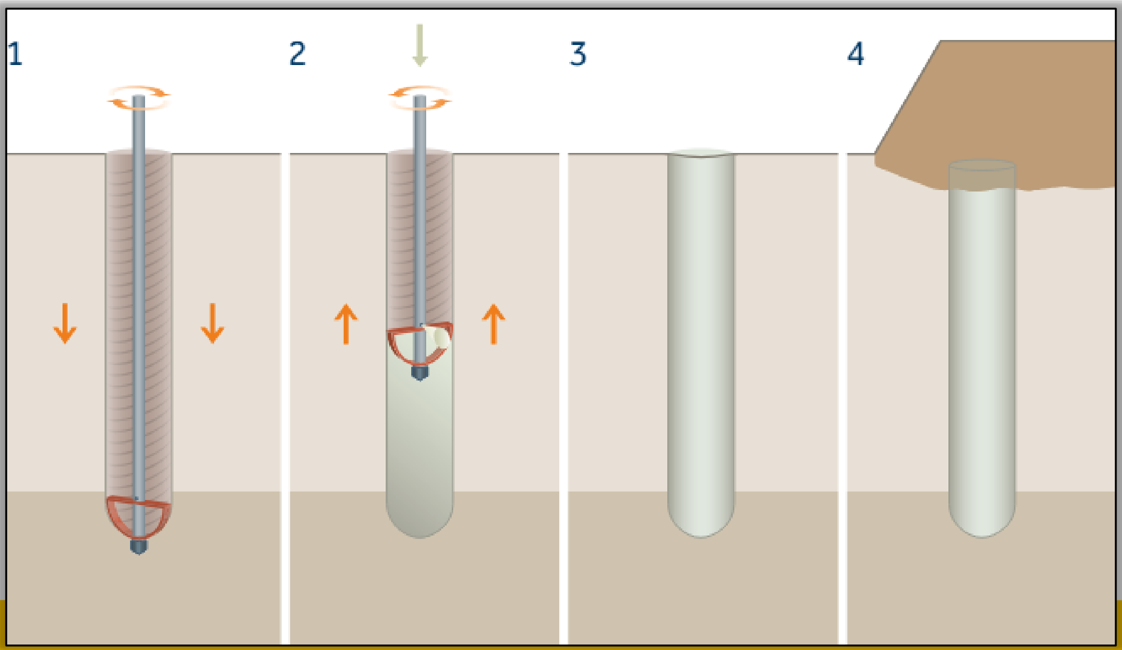


Soil Mixing

- **TRD** allows **a homogeneous vertically mixed wall. Installation up to 150 feet**
- Wet or dry soil mix columns **can be installed in a single column arrangements or using multi axis as a slurry during the mixing**
- **Mass mixing treatment depth is limited to 20 feet.**







Limitations of Soil Mixing

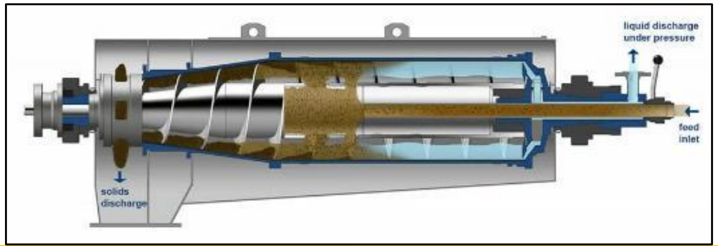
- **Depth Constraints:** most effective for shallow to medium depths.
- **Soil Compatibility:** Some soils are naturally too **coarse, too organic, or contain too much stiff clays** that hinder the mixing process.
- **Site Access and Space:** deep soil mixing equipment is large and requires sufficient space to operate. Limited access or congested areas can be problematic.
- **Energy Consumption and Emissions Control Measures are needed to comply with regulations.**
- **Waste Management:** handling of excess soil and spoils

1. Core Rig
2. Pre-Drill
3. Batch Plant
4. DSM Rig
5. Cement Delivery
6. Spoils Loader

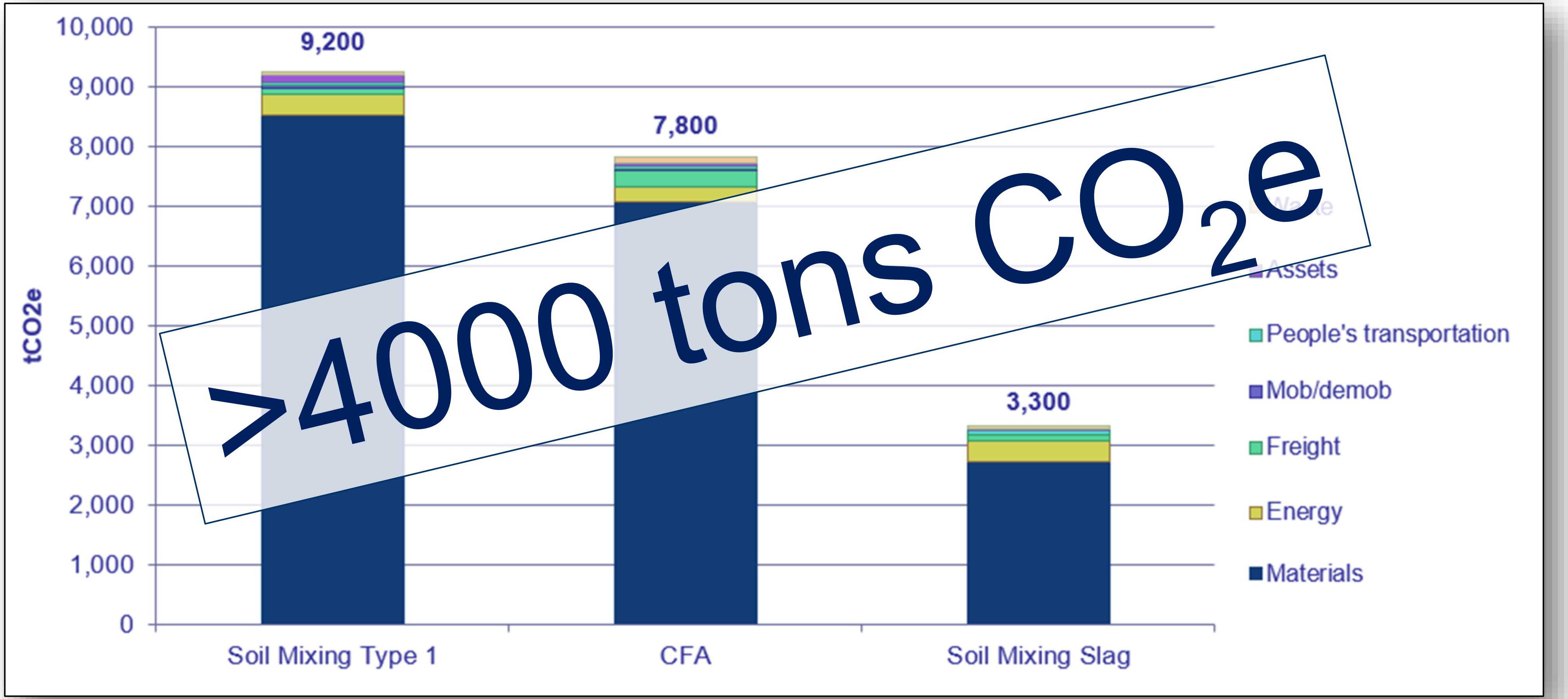
Spoils Management

Treating spoil on site: desander

- **Remove coarse fraction from spoil**
- **Processed slurry pumped to centrifuge for further treatment**
- Centrifugal forces separate fines from spoils. **Majority of solids can be removed.** Optional use of flocculants for best results.
- **Discharged water can be reused in slurry production or discharged into sewer system**



CFA to Soil Mixing



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