Understanding of Foundations: Success of a Civil Engineer…!

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IIT Gandhinagar

Introduction of Keller
Keller Group - History of Keller

### Acquisitions

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
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<tbody>
<tr>
<td>1960</td>
<td>Expansion into a UK national piling &amp; ground improvement company.</td>
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<tr>
<td>1974</td>
<td>Acquired Johann Keller in Germany marking international expansion.</td>
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<tr>
<td>1984</td>
<td>Acquired Hayward Baker (US).</td>
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<tr>
<td>1990</td>
<td>Management buyout from GKN plc.</td>
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<td>1994</td>
<td>Acquired Case (US).</td>
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<td>2001</td>
<td>Acquired Suncoast (US).</td>
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<td>2006</td>
<td>Acquired Piling Contractors (Australia).</td>
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<tr>
<td>2009</td>
<td>Acquired Resource Piling (Singapore).</td>
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<tr>
<td>2010</td>
<td>Acquired Waterway Constructions (Australia).</td>
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<tr>
<td>2013</td>
<td>Acquired Geo Foundations (Canada).</td>
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<tr>
<td>2010</td>
<td>Acquired Keller Canada (Canada).</td>
</tr>
<tr>
<td>2013</td>
<td>Acquired Franki Africa (South Africa).</td>
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</tbody>
</table>

### Key Milestones

- **1958**: Est. 1958 Ground test services
- **1960’s**: Expansion into a UK national piling & ground improvement company
- **1984**: Acquired Hayward Baker (US)
- **1994**: Acquired Case (US)
- **2001**: Acquired Suncoast (US)
- **2002**: Acquired McKinney (US)
- **2006**: Acquired Piling Contractors (Australia)
- **2007**: Acquired H.J. Foundation (US)
- **2009**: Acquired Resource Piling (Singapore)
- **2010**: Acquired Waterway Constructions (Australia)
- **2013**: Acquired Geo Foundations (Canada)
- **NOW**: c. 9,000 employees
- **2001**: 40 Countries of Operations
- **2002**: 10,000 Employees
- **2002**: ₹16,000 Cr. Turnover

### Activities

- **51%**: PILING
- **20%**: GROUND IMPROVEMENT
- **10%**: SPECIALTY GROUTING
- **10%**: ANCHORS, NAILPILES
- **9%**: POST TENSION CONCRETE

### Locations

- **North America**: USA & Canada
- **EMEA**: Europe, Middle East, Africa & Latin America
- **APAC**: Asia-Pacific region

### Turnover Breakdown

<table>
<thead>
<tr>
<th>Region</th>
<th>Percentage</th>
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<tbody>
<tr>
<td>PILING</td>
<td>51%</td>
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<tr>
<td>GROUND IMPROVEMENT</td>
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<td>SPECIALTY GROUTING</td>
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<td>ANCHORS, NAILPILES</td>
<td>10%</td>
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<tr>
<td>POST TENSION CONCRETE</td>
<td>9%</td>
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</table>
Asia-Pacific

Keller Foundations S.E.A. Pte Ltd., Singapore
Resource Piling Pte. Ltd., Singapore/Malaysia
Keller Ground Engineering India Pvt Ltd.
Keller (M) Sdn. Bhd., Malaysia
Ansah Asia Sdn. Bhd., Malaysia
Keller Foundations Vietnam Co., Ltd
Keller Foundations S.E.A. Pte Ltd., Indonesia
PT. Frankipile Indonesia
Keller Ground Engineering Pty Ltd, Australia
Keller Foundations, Australia
Frankipile Australia Pty Ltd
Vibropile (Australia) Pty Ltd
Piling Contractors Pty Ltd, Australia
Waterway Constructions Pty Ltd, Australia
Austral Construction Pty Ltd
Keller New Zealand

Presence in India

- Ongoing Projects
- Completed Projects
- Keller Offices
Product Portfolio

Foundation Services

Ground Improvement
- Vibro Compaction
- Wet Vibro Stone Columns
- Dry Vibro Stone Columns (Vibrocat & Alpha S)
- Vibro Sand Columns

Heavy Foundation
- Bored Piles
- Contiguous Bored Piles
- Diaphragm Wall
- Sheet Piles

Small Diameter
- Ground Anchors
- Micro Piles
- Compaction Grouting
- Permeation Grouting

Foundation Civil Works
- Foundation Interface (Raft & Pile Caps)
- Tank Sand Pads
- Earth works
- Approach Road Works

Client Portfolio

- International
- Indian Government Owners
- Local Big Private Owners
- Local Big Main Contractors
- Local Entrepreneurs

Contributed in building 3 LNG Terminals, 3 Large Refineries, 200 Storage Tanks, 10,000 MW Power Plants, 6 Sea Ports, 20 Metro Stations, 2 Air Ports and Real Estate developments
Understanding of Foundations: Success of a Civil Engineer....!

What is Soil Structure Interaction......?

Understanding of Poor Soils
Poor Soils

Loose sands
- Usually reclamation fills (recent fills)
- CPT q_c: < 6 MPa, Friction ratio < 1%
- Relative density: 30 to 40%
- Typical depths: 10 to 30m

Challenges:
Bearing Capacity
Settlement
Liquefaction

Poor Soils

Loose silty sands
- Alluvial deposits
- E.g. river delta
- Silt & clay content < 20%

Challenges:
Bearing Capacity
Settlement
Liquefaction
Poor Soils

- Soft and “ultra-soft” silts
  - Usually sedimentation deposits
  - $c_u = 5$ to 20 kPa

Challenges:
- Bearing Capacity
- Settlement

Poor Soils

- Soft and very soft marine clays
  - Found in coastal areas
  - SPT N = 1 to 2 blows
  - Permeability, $k = 10^{-8}$ to $10^{-9}$ m/sec
  - Plasticity Index > 50%

Challenges:
- Bearing Capacity
- Settlement
Poor Soils

- **Organic soils, Peats**
  - Naturally formed, of decayed vegetation
  - Cause for concern: Organic content > 10%
  - Engineering concern: stability of foundations/structures

- **Municipal Wastes, Landfills**
  - Manmade
  - Locations: metropolitan cities, dumping yards

**Challenges:**
- Bearing Capacity
- Settlement
- Overall stability
- Liquefaction

What are the troubles with poor soils....?

- Low [Bearing Capacity](#) of foundation soils
- [Settlement](#) due to weak layers
- [Slope Stability](#) of high embankments
- [Liquefaction](#) during earthquakes
Understanding of soil structure interaction.....

What are the consequences?
Irreversible differential settlements, damage to the structure
energy dissipation

Dynamic structural response

Soil-foundation interaction

Site amplification
Depending on topography and stratigraphy

The response of a structure to earthquake shaking is affected by interactions between three linked systems:
1) the structure,
2) the foundation, and
3) the geologic media underlying and surrounding the foundation.

SSI effects reflect the differences between the actual response of the structure and the response for the theoretical, rigid base condition.

[Fig. from H. Allison Smith & Wat-Hora Wa, 1997]
Today’s take home…

- Understanding of behaviour of foundations (15 min)
- Engineer’s Choice of Foundations (15 min)
- Ground Improvement Techniques (40 min)

Behaviour of foundations…
Bearing Capacity Failures

Settlement Failures (Illustration 1)
Settlement Failures (Illustration 2)

Types of settlement

- uniform settlement (no cracks)
- tipping settlement (often without cracks)
- differential settlement (with cracks)

Slope Stability (static or seismic)

- Settlement
- Embankment
- Lateral Spread
- Liquefied Stratum
Liquefaction

- Liquefaction is a phenomenon in which the strength and stiffness of a soil is reduced due to earthquake shaking or due to other rapid loading.
- Liquefaction occurs in saturated soils
- Soil particles lose contact with each other
- Earthquake shaking cause increase in water pressure to the extent where the soil particles readily move (float) with respect to each other

3 factors required for liquefaction to occur
1) Loose, granular sediment
2) Water saturated sediment
3) Strong shaking

San Francisco, 1906
How to Address Geotechnical Challenges…..?

Options for Intelligent Engineer:

- Savings in construction cost
- Fast completion (savings in time)
- Savings in materials & less carbon footprint

What does this mean to a civil engineer…..?
Engineer’s Choice of Foundations…

Ground Engineering & Foundation Systems
Part A: Ground Improvement Techniques

What is Ground Improvement...?

Ground improvement is defined as the controlled alteration of the state, nature or mass behavior of ground materials in order to achieve an intended satisfactory response to existing or projected environmental and engineering actions.

Source: CIRIA Publication
Types of Ground Improvement

♦ Densification
  • Principle: Reduction of voids between particles (coarse grained soils)
  • Example: Vibro Compaction, Blast Densification, Compaction Grouting

♦ Reinforcement
  • Principle: Introduction of reinforcing element to carry the loads
  • Example: Vibro stone columns, geogrids

Types of Ground Improvement

♦ Consolidation
  • Principle: Shortening of Drainage Paths + Increase of Effective Stress
  • Example: PVD + Surcharge; Vacuum Consolidation

♦ Chemical Modification
  • Principle: Introduction of Chemical Binder that causes with time
  • Example: Injection Grouting, Deep Mixing, Jet Grouting
Ground Improvement Methods

Densification
- Vibro Compaction
- Dynamic Compaction
- Blast Densification
- Compaction Grouting

Consolidation
- PVD + Surcharge
- Vacuum Consolidation
- Vibro Replacement

Chemical Modification
- Deep Soil Mixing
- Jet Grouting
- Permeation Grouting
- Compaction Grouting

Reinforcement
- Vibro Replacement
- Geosynthetic Reinforcement
- Rigid Inclusions

Others
- Removal & Replacement
- Thermal
- Electrical

Deep Vibro Techniques
Concept of Deep Vibro Techniques

Before

After

Vibro Compaction (VC)

Vibro Replacement (VR)

Density of Soil

Process of Vibro Compaction
Process of Vibro Stone Columns

Wet Top Feed Method

Dry Bottom Feed Method

Process of Vibro Compaction
Process of Vibro Stone Columns

Mechanism of working of stone columns
Unit cell concept

Area Replacement Ratio (ARR)

- Key index for effectiveness of improvement
- Area Replacement Ratio (ARR) = Area of column, $A_c$/Area of grid, $A$

For 2.2m x 2.2m grid (Area of grid, $A = 4.84 \text{ m}^2$).
- Area of 1.0m diameter column, $A_c = 0.785 \text{ m}^2$ ⇒ ARR ~ 16%
Concept of soil model

- Improved ground is considered as a composite ground with composite/improved parameters.

**Weak Ground**
- $s_u = 10 - 20$ kPa
- $\Phi = 0^\circ$
- $D_s = 1 - 4$ MPa

**Stone Columns**
- $\Phi = 42^\circ - 44^\circ$
- $D_s = 100 - 150$ MPa

“Composite parameters”
- $c' = 5 - 10$ kPa
- $\Phi' = 20^\circ - 30^\circ$
- $D_s = 3 - 10$ MPa

Design Methodology (Priebe’s)
**How do vibro stone column works?**

<table>
<thead>
<tr>
<th>Key mechanism</th>
<th>Settlement control</th>
<th>Increased Stability/ bearing capacity</th>
<th>Accelerated consolidation</th>
<th>Liquefaction mitigation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reinforcement</td>
<td>Reinforcement</td>
<td>Shortened drainage path</td>
<td></td>
<td>Reinforcement + shortened drainage path</td>
</tr>
<tr>
<td>Key properties</td>
<td>Stiffness, diameter, length, area ratio</td>
<td>Stiffness, diameter, area ratio</td>
<td>Diameter, length, area ratio, column material</td>
<td>Stiffness, diameter, area ratio, column material</td>
</tr>
<tr>
<td>Controls</td>
<td>Construction amps, “termination” amps, column length, column continuity, stone consumption, column numbering, stone grading curve</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other considerations</td>
<td>Rate of loading</td>
<td>Drainage platform quality</td>
<td>Lateral extent of treatment zone</td>
<td></td>
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</table>

**Choice of Technique**

- **Suitability of technique**
  - Is the soil and the technique *fundamentally* compatible?
- **Technical compliance**
  - Does the technique provide the strength, stiffness or permeability required?
- **Availability of material**
  - Is the material (stone, cement, geotextile) readily available?
- **Cost**
  - Is it within budget?
- **Protection of the environment**
  - Does the technique reduce or avoid pollution? Is the technique resource efficient?
Applications

Embankments

Buildings

Reinforced soil walls

Airport Runways

LNG Tanks

Part A: Ground Improvement Techniques: Case Studies

A. Improving Bearing Capacity : Case Study 1
B. Settlement Control : Case Study 2
C. Liquefaction Mitigation : Case Study 3
D. Liquefaction, BC & Settlements : Case Study 4
E. Industrial structure : Case Study 5
A: Improvement of Bearing Capacity

- **Project**: Tank Farms at HPCL Terminal, Ennore, Chennai
- **Structure**: Tanks (max. 32m dia & 15m height)
  - 18 - Floating roof storage tank
  - 4 - Fixed roof storage tank
  - 3 - Fire water tanks
- **Bearing Capacity**: 20T/m²

**Challenges:**
- Bearing Capacity
- Settlement

**Technical Solution**

- **Type of GI**: Wet Vibro Stone Columns
- **Area Replacement**: 25%
- **Interface**: Sand Pad
Performance

- Improved BC: 20T/m²
- Settlement: < 300mm (during Hydro test with full load)

Completed Structure

- In India, Over 200 Tank Foundations are built successfully on Ground Improvement at various Tank Farms (HPCL, IOCL, MRPL, SHELL LNG, etc.)
B: Liquefaction Mitigation

- **Project**: Construction of Indira Sagar Polavaram Dam at Andhra Pradesh
- **Structure**: Multipurpose Dam across the River Godavari near Polavaram village
- **Relative density**: < 60 %
- **Seismic Zone**: Zone III

**Challenges:**
- Liquefaction
- Bearing Capacity

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**Dam layout & Plan view**

[Map of Indira Sagar Polavaram Dam project layout and plan view]
Typical Cross Section of ECRF Dam

Soil Profile across the dam
Technical Solution

Vibro Compaction
Vibro Compaction Works

Performance

(a) Average estimated relative density profile for in-situ and improved ground

(b) Average estimated relative density profile for in-situ and improved ground

Chainage: 450 m to 580 m

Chainage: 680 m to 980 m
C: Settlement Control

- Project: Urban Tree Residential Project "INFINITY" Chennai
- Structure: Stilt + 4 floors with 198 flats in over site area of 2.5 acres
- Settlement: < 100mm as per IS 1904-1986

**Challenges:**
Settlement
Bearing Capacity

**Vibro Stone Columns**
Technical Solution

- Type of GI: Dry Vibro Stone Columns
- Area Replacement: 20%
- Interface: Raft

Performance

- BC of improved ground: > 15T/m²
- Long-term settlement: < 100mm (monitoring for past 1 year)
Completed Structure

- Dry Vibro Stone Columns as Optimal Foundation Solution alternative to Piling
- Delivered Foundation works in 6-weeks instead of 6-months for Piling solution

D: All Applications (SBC, Settlement & Earthquake)

- Project: Umang Realtech Pvt Ltd, ‘SUMMER PALM’, Haryana
- Structure: Stilt + 14 floors over site area of 12 acres
- Bearing capacity: 15 T/m2
- Settlement: < 100mm as per IS 1904-1986
- Seismic Zone: Zone IV, 0.24 g

Challenges:
Bearing Capacity
Settlement
Liquefaction
Vibro Stone Columns

Technical Solution

- Type of GI: Dry Vibro Stone Columns
- Area Replacement: 20%

![Diagram of Vibro Stone Columns]
Performance

![Graph showing settlement vs load]

<table>
<thead>
<tr>
<th>Load Intensity</th>
<th>Settlement @ Design Load</th>
<th>Net Settlement</th>
<th>All. Settlement as per IS 15284 (Part 1): 2003</th>
</tr>
</thead>
<tbody>
<tr>
<td>150 kPa</td>
<td>10.2 mm</td>
<td>6.7 mm</td>
<td>30 mm</td>
</tr>
</tbody>
</table>

Completed Structure

![Completed structure image]
E: Industrial Structure (SBC, Settlement & Earthquake)

- Project:
- Structure:
- Bearing capacity: 15 T/m²
- Settlement: < 100mm as per IS 1904-1986
- Seismic Zone: Zone IV, 0.24 g

Challenges:
Bearing Capacity
Settlement
Liquefaction

Vibro Stone Columns
Technical Solution

- Type of GI: Dry Vibro Stone Columns
- Area Replacement: 20%

Performance
Deep Soil Mixing

Concept of Deep Soil Mixing

- Strengthens / stiffens the in-situ soil
- Results in relatively rigid foundation system
Process of Deep Soil Mixing

1. Mechanical Cutting
2. Mechanical Mixing
3. Full Completed DSM Column
Applications

- Improving Bearing Capacity
- Settlement Control
- Excavation Support

Earth Retention – Physics
Excavation Support – Bending Rigidity

- Project: Construction of Music Academy, Poland
- Structure: Music Academy, Poznan, Poland

Excavation Support System: *Strut-free Concept*

- DSM with I sections

Challenges:
- Overall Stability of Excavation

Technical Solution

- Type of GI: Compound DSM (DSM + I-Sections)
- Depth of Treatment: 10m
Excavation Support – Bending Rigidity
Excavation Support – Gravity Wall

- Project: Fraser Biz Park, Kuala Lumpur
- Structure: Commercial Complex (2B+G+3F)
- Excavation Depth: 7m (perimeter ~ 700m)

**Challenges:**
Overall Stability of Excavation

Technical Solution

- Type of GI: DSM Gravity Wall
- Depth of Treatment: 8m
- Designed UCS value: 1MPa
Excavation Support – Gravity Wall

- Achieved UCS value ~ 1-3MPa
- Observed Movement ~ 20mm

Grouting Techniques
Concept of Grouting

- “Grouting in ground engineering can be defined as controlled injection of material, usually in a temporary fluid phase, into soil or rock, where it stiffens to improve the physical characteristics of the ground for geotechnical engineering applications”

- “Grouting techniques started from practice, not from theory”

Grouting Techniques

- **Rock Grouting**: Filling of fractured rock with grout
- **Perm. Grouting**: Penetrating the voids with grout
- **Comp Grouting**: Displacement of soil with grout
- **Jet Grouting**: Eroding and mixing the soil with grout
Applications

• Seepage Control
• Soil Arching
• Settlement Control
• Impermeable deep cut-off

Seepage Control – Permeation Grouting

• Project: Construction of Low Dam IV for Hydro Power Plant, WB
• Structure: Teesta Low Dam IV

Challenges:
Seepage Control
(permeability requirement of $10^{-6}$ m/sec)
Technical Solution

- Type of GI: Permeation Grouting
- Depth of Treatment: 22m

Performance
Soil Arching – Compaction Grouting

- Project: DMRC Saket, Delhi
- Structure: Twin Shaft NATM Tunnel for Metro Rail
- Soil Arching: To support 8m dia NATM Construction

**Challenges:**
Soil Arching (Settlement Control)
Technical Solution

- Type of GI: Compaction Grouting
- Mix ratio: 1:3 Cement Mortar
- Depth of Treatment: 8m

Performance

- Post SPT N value ~ 20 to 30 (above requirement line)
- As SPT value increases lateral confinement also increased to ensure required Soil Arching
Impermeable deep cut-off – Jet Grouting

- Structure: Cut-off wall for Cofferdam

What is Jet Grouting (Soilcrete)?

- Jet Grouting is a process consisting of the disaggregation and partial displacement of soil and its mixing by a cementing agent.
- The disaggregation is achieved by a high energy jet of a fluid which can be the cementing agent itself or water.
- Jet grouting can be executed using
  - T-System (0.8m to 1.2m dia.)
  - D-System (1.5m to 2.2m dia.)
Process of Jet Grouting (Soilcrete)

Jet Grouting (Soilcrete) Systems

**T-System**
Triple fluid system erodes the soil with an air shrouded water jet of min. 100 m/sec exit velocity. Grout is injected simultaneously through an additional nozzle located below the water jet nozzle.

**D-System**
Double Direct Process – operates with a grout jet of min. 100m/sec exit velocity for simultaneous cutting and jetting of the soil.
Proposed Scheme

Large Diameter

Deviated Jet Grouted Column (Typ) – No Gap between the columns.

Typical Drilling Operation
Jet Grouting Plant & Equipment

Typical Jet Grouting Pump
Typical Site Set Up

QA - Site Validation Testing
Project Photographs

Compaction & Jjef Grouting for Faraday Launching Shaft

Conclusions

• Ground Improvement Techniques can be used to provide Optimal Solutions

• Design & Build expertise will ensure savings in Cost & Time

• Execution of Specialized Foundation Techniques requires state-of-the-art experience with Operational Excellence and Best Practices

• International standard of practices using latest equipment ensures the success of a project

• Safety goal of zero accidents is possible with dedicated safety systems and motivated leadership
Keller’s Ideal Worker (Kelwin)

All the best & Good Luck…..!
Thank you for your kind attention......!