Ground Engineering Solutions for Infrastructure Projects: Case Studies

Singapore  Malaysia  Resource Piling  India  Hong Kong  Indonesia

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Keller India

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Ground Engineering & Foundation Systems

Foundation Engineering

- Shallow Foundations
  - Foundations on Natural Soils (Un-Improved Soils)
    - Good Bearing Strata
    - Less Load Intensity
    - Settlements within Tolerable Limits
  - Foundations on Weak Soils (Improved Soils)

- Deep Foundations
  - Bored Cast In-Situ Pile Foundations
    - Friction Piles
    - End Bearing Piles
    - Friction & End Bearing Piles
  - Driven Pile Foundations
    - Steel Piles
    - Pre Cast Piles
    - Driven Cast In-Situ Piles

- Ground Improvement Techniques
Principles & Types of Ground Improvement Techniques

Concept of 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
Principles of Ground Improvement

- **Densification** *(loose sands)*: rearrangement of granular particles
- **Consolidation** *(Cohesive)*: drainage and reduction of voids
- **Chemical Modification**: hardening by addition of binders
- **Displace & Reinforce**: pushing unsuitable soils aside, installing stiffer elements

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
  - Injection Grouting

- **Reinforcement**
  - Vibro Replacement
  - Geosynthetic Reinforcement
  - Rigid Inclusions
  - (Compaction Grouting)

- **Others**
  - Removal & Replacement
  - Thermal
  - Electrical
  - Electrical
Ground Improvement: Soil Dependency

- **PILES** (bridge over weak soil)
- **REINFORCED GI TECHNIQUE** (treat weak soil + strengthen with stones, cement, etc.)
- **UNREINFORCED GI TECHNIQUE** (consolidation by weight)

Ground Improvement: Suitability

- **PILES**
- **GROUND IMPROVEMENT TECHNIQUES**
- **CONSOLIDATION BY SURCHARGE**
Under the influence of the induced vibration, the soil particles within the zone of influence are rearranged and compacted.

"Deep Vibro techniques" which utilize the energy of a depth vibrator.

Vibro Techniques

Vibro Replacement

Install compacted granular columns in all types of soils, referred to as Vibro Replacement.

Vibro Compaction

Before and After

Vibro Compaction
Schematic of Vibro Compaction

Ground Subsidence during Vibro Compaction
Vibro Stone Columns – Concept

- Displacing the soil radially with the help of a depth vibrator, refilling with granular material and compacting
  - Increases the density of the soil between the columns
  - Provides drainage
  - Increases stiffness of the soil

Vibro Stone Columns

Before Treatment

After Treatment

Wet Top Feed Method

Dry Bottom Feed Method
Wet Top Feed Method

Dry Vibro Stone Columns – Process
Dry Vibro Stone Columns – Execution

Quality Control Measures – Pre and Post

- Automated Real Time Monitoring of Installation Process
- Reliable investigation techniques (Electric Cone Penetration Testing, SPT’s etc)
- Post improvement testing by Load Tests
- Good quality of Back Fill Material
Deep Soil Mixing

Mechanical mixing of in-situ soils with a binder (e.g. cement, slag, lime, fly ash etc.) to improve shear strength and to reduce permeability of weak deposits.

**Mechanical Cutting**

**Mechanical Mixing**

**Full Completed DSM Column**

**DSM Operation in field**

Deep Soil Mixing

Very Soft Clay / Slime  
Cu = 5 to 10 kPa

Pile Like Element  
Cu = 100 to 2000 kPa
Grouting Techniques

Introduction of liquid or dry binder (esp. cement material) into the weak soil mass, to improve its strength, stiffness and reduce permeability.

<table>
<thead>
<tr>
<th>Technique</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soilcrete&lt;sup&gt;TM&lt;/sup&gt; Jet Grouting</td>
<td>Eroding and mixing the soil with grout</td>
</tr>
<tr>
<td>Grouting</td>
<td>Penetrating &amp; filling soil voids with grout</td>
</tr>
<tr>
<td>Soilfrac&lt;sup&gt;TM&lt;/sup&gt; Compensation Grouting</td>
<td>Fracturing &amp; Heaving of the soil with grout</td>
</tr>
<tr>
<td>Compaction Grouting</td>
<td>Compaction/ Densification of soil with stiff grout bulb</td>
</tr>
</tbody>
</table>

Choice of Technique

- **Suitability of Technique**
  - Are the encountered soil and suggested technique fundamentally compatible?

- **Technical Compliance**
  - Does the suggested technique satisfy the design requirements? (strength or stiffness?)

- **Availability of Material**
  - Is the required material (stone, cement) readily available?

- **Cost**
  - Is the proposed technique within the budget? What is the cost of time when there is saving?

- **Protection of the Environment**
  - Does the suggested technique reduce or avoid pollution? Is the technique resource efficient?
Geotechnical Challenges in Infrastructure Projects

Case Studies

Geotechnical Challenges (esp. for Infra Projects)

Variation in Subsurface Geology
- Weak deposits / marine deposits / reclamation
- Design soil profile & parameters
- Selection of suitable foundation
- Fulfilling structural requirements
- Alternative foundation systems

Technical Expertise

Innovative Technology
- Alternative Design & Build Solutions
- Liquefaction Mitigation
- Innovative techniques
- Savings in Cost and Time
- Cost Effective Foundations are Key to Success

Design & Build Expertise

Execution Challenges (BCIS Piles)
- Borehole stability
- Knowledge on Drilling Fluid
- Effective usage of stabilizing fluid
- Quality Control

Operational Excellence
Technical Expertise: Infrastructure Projects on Weak Deposits

Design Challenges
- Weak deposits / marine deposits / reclamation
- Design soil profile & parameters
- Selection of suitable foundation
- Fulfilling structural requirements
- Alternative foundation systems

Power Plant in UP

Project: 2 x 500MW Thermal Power Plant (Unit D)
Owner: Uttar Pradesh Rajya Vidyut Utpadan Nigam Ltd (UPRVUNL)
Location: Anpara, near Sonebhadra (U.P)
Structures: Coal Handling Plant
: Water System Package
: Substation (760 kV)
Construction Site: Abandoned Fly Ash Deposit resting on Clay Layer
Confirming Design: Deep Foundations to address Vertical & Lateral Loads
Soil Conditions (Typical)

Challenges
- **Bearing Capacity**: < 10T/m² (required > 10 T/m²)
- **Low lateral capacity**: < 2 T for BCIS Piles (desired > 7T)
- **Liquefaction**: Zone III, Possibility of liquefaction

Geotechnical Solutions

**General Approach:**
- Deep Foundations: for Settlement sensitive structures (Stacker Reclaimer)
- Shallow Foundations: for lightly loaded structures Pump House, Drive House, Cable Gallery, Sub-Station etc.

**Geotechnical Value Addition:**
- Combination of Ground Improvement & Bored Piles
- Ground Improvement using Vibro Stone Columns (dry bottom feed method) was suggested
  - To enhance Bearing Capacity > 10T/m² for Open Foundations
  - To enhance Lateral Pile Capacity of bored piles to 7T
  - To mitigate the Liquefaction potential
- Extensive research by IIT Roorkee

**Result of Technical Expertise:** Savings in Cost & Time
Addressing Bearing Capacity

- Ground Improvement using Vibro Stone Columns (dry bottom feed method)
- Stone columns terminated into the underlying stiff clayey silt or silty clay
- Single and group column load tests were conducted to ensure performance

Addressing Lateral Capacity of Piles

- Stone Columns of 0.5m dia. installed at the centre and surrounding two piles
- Stone Column of 0.5m dia. installed at the centre and 0.75m dia installed surrounding two piles
Addressing Lateral Capacity of Piles

- The deformations observed to be within allowable limits (5mm) at design load of 7T
- 0.5m dia. stone column grid was adopted for main works

![Lateral Pile Load Test Results](image)

Installation of Stone Columns & Bored Piles

![Installation of Stone Columns & Bored Piles](image)
**Design & Build Expertise:** Innovative Technology

Innovative Technology
- Alternative Design & Build Solutions
- Liquefaction Mitigation
- Innovative techniques
- Savings in Cost and Time
- Cost Effective Foundations are Key to Success

- Industrial Plant @ Singapore
- Industrial Plant @ Hajipir
- Multi-storeyed tower @ NCR
- Residential building @ Chennai
- Wind Turbines @ Kolhapur

**Opportunities for Optimization**

**Definition:**
Alternative or approach that **best fits** the situation, employs resources in a most **effective and efficient** manner, and yields the highest possible return under the given circumstances.

**Approaches**

- **Good data**
  - Extensive Soil Investigation
  - Real / Factual Soil Data

- **Physics**
  - How are forces resisted

- **Materials**
  - Carbon footprint, muck disposal

- **Cost**
  - Savings in materials

- **Time**
  - How long do you take

(Soil Data) (Analysis & Design) (Environment) (Foundation Optimization) (Savings in Time)
**Design & Build Expertise:** Innovative Technology

- Alternative Design & Build Solutions
- Liquefaction Mitigation
- Innovative techniques
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**Industrial Plant @ Singapore**
- Industrial Plant @ Hajipir
- Multi-storeyed tower @ NCR
- Residential building @ Chennai
- Wind Turbines @ Kolhapur

Factories on Reclaimed Soil – Shipyard

- **Land reclamation**
  - *Fill thickness 5m to 30m*
  - *Qc about 4 to 6 MPa*
  - *RD about 30% to 40%*
Factories on Reclaimed Soil – Structure

Hull shop

- Automated steel plate cutting and assembly
- 180m x 670m
- 50m tall

Factories on Reclaimed Soil – Structure

- Foundation for columns
- Foundation for floor slab
Factories on Reclaimed Soil – Structure

Automation => Sensitive to settlements

Factories on Reclaimed Soil – Loading

Settlements
- Steel Storage Area < 100mm
- Other Areas < 50mm
- Differential ≈ 1 in 1000
Factories on Reclaimed Soil – Soil Investigation

Collect Extensive Soil Information

Legend
- Existing Boreholes (56 nos)
- Existing CPT
- Additional Boreholes
- Additional CPT (> 60 nos. – more where you need them)

Factories on Reclaimed Soil – Soil Conditions

Loose reclaimed SAND
Stiff to very stiff clay
Soft to firm clay
Hard clayey silt
Factories on Reclaimed Soil – Geotechnical Solution

Conforming : Driven Piles

Factories on Reclaimed Soil – Site
Factories on Reclaimed Soil – Testing

Post CPT

Factories on Reclaimed Soil – Shipyard

• Physics (NSF)
• Cost
• Time
• Materials & Carbon Footprint
**Design & Build Expertise:** Innovative Technology

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**Project Background**

- **Project:** Chemical Plant
- **Location:** Kutch region, Gujarat State, India
- **Structures:** Industrial Structures
- **Plot Area:** 25 Ha.

**Main Structures:**
- Sulphate of Potash (SOP)
- Bromine Plant
- Cogen Plant

**Other Structures:**
- Storage Tanks
- Workshops
- Treatment Plants
- Ancillary structures and other Amenities
- Buildings and other Storage Areas
Soil Data and Loading Conditions

**Soil Data**
- Boreholes were explored to a depth of 20m to 25m below EGL and Uniform Soil Conditions throughout the site.
- Top 6m: Silty CLAY, SPT N is < 6
- 6m to 15m: Silty Sand with clay, N ≈ 40
- 15m to 25m: Hard Silty Clay, N > 50
- GWT was at 2m below EGL

**Loading Conditions**
- Foundation type: Piles for heavily loaded Structures, Raft for light to medium loaded Structures
- Loading Intensity: 100 kPa to 200 kPa
- Settlement criteria: < 100 mm (for shallow foundations)

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Optimal Solution with Savings in Time

**Confirming Design by the Developer:**
- Bored Cast In-Situ Piles: (750mm dia. 24m depth, 2000 nos.)
- Construction Time: 16 months
- Foundation Cost: INR 850 mio. (Piling + Pile Caps + Others)

**Alternative Design by Keller:**
- Bored Cast In-Situ Piles: (750mm dia. 16m depth, 700 nos.)
- GI Technique: Vibro Stone Columns (dry bottom feed technique)
- Dia. & Pattern: 900mm dia. 1.7m to 1.9m c/c, 6m depth, 100,000 sqm
- Construction Time: 10 months
- Foundation Cost: INR 45 mio. (GI + Granular Blanket + Raft Foundation)

**Advantages to the Investor:**
- Very good amount of Savings in Cost (50%)
- Savings in Time for about 6 months
- Reduced Carbon footprint
- Locally available stone material (avoided usage of large quantity of cement and steel)
- Early Completion of Project (benefit to Investor by saving site OH + benefit to Banker by early disbursement of Loans => Early commissioning of Plant)
Cost Effective Alternate Solutions

- **Pile Foundations**
  - Sulphate of Potash (SOP)
  - Bromine Plant
  - Cogen Plant

- **Shallow Foundations on GI**
  - Storage tanks
  - Workshop
  - Treatment Plant
  - Ancillary structures and amenities
  - Buildings and other storage areas

Foundation Alternatives & Performance

- **Heavily loaded structures** were supported on 750mm dia. and 16m long BCIS Piles
- **Lightly loaded structures** were rested on GI using Vibro Stone Columns (dry bottom feed method)
- **Load Tests** were conducted on Piles & GI and performance proved satisfactory.
Sulphate of Potash Plant (25m tall)

Completed Plant Structures
Design & Build Expertise: Innovative Technology

Innovative Technology
- Alternative Design & Build Solutions
- Liquefaction Mitigation
- Innovative techniques
- Savings in Cost and Time
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Industrial Plant @ Singapore
Industrial Plant @ Hajipir
Multi-storeyed tower @ NCR
Residential building @ Chennai
Wind Turbines @ Kolhapur

Tall buildings on GI, Umang Realtech, India
Project Background

- Project: Summer Palm
- Location: NCR Region
- Building: G + 14 floors, 13 Towers
- Raft Area: 12,000 sq.m
- Plot Area: 12 Acres

Soil Data & Loading Conditions

Soil Data
- Boreholes were explored to a depth of 20m to 25m below EGL and Uniform Soil Conditions are found throughout the site.
  - Top 7.5m: Silty SAND, SPT N varies from 6 to 17
  - 7.5m to 10.5m: Loose med. Sandy SILT, N ≈ 17 to 23
  - 10m to 20m: Med. Dense Sandy SILT, N > 40
  - GWT was at 2m below EGL during investigation

Loading Conditions
- Foundation type: Raft
- Loading Intensity: 150 kPa
- Settlement criteria: < 75 mm
Bearing Capacity & Liquefaction

Main Technical Concerns are………………
- Low Bearing Capacity due to weak soil
- Total & Differential Settlements
- Mitigating Liquefaction (Zone 4, 0.24g)

Required Geotechnical Solution………
- Reinforcement
  - To improve composite shear strength
- Compaction in granular/soft subsoil
  - To increase composite compression modulus
- Large Drainage path
  - To improve overall permeability
- Mitigate Liquefaction

Proposed Ground Improvement Scheme

- Vibro Stone Columns with Dry Bottom Feed Technique
  - Column diameter = 900mm
  - Grid pattern = Square grid
  - Column spacing = 2.0m c/c
  - Treatment depth = 8m below EGL
  - Area replacement = 16%
Site View (during execution)

Group Load Test & Performance

<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>

![Load vs Settlement](chart.png)

Key note lecture DFI Chennai 2012
Design & Build Expertise: Innovative Technology

Innovative Technology
- Alternative Design & Build Solutions
- Liquefaction Mitigation
- Innovative techniques
- Savings in Cost and Time
- Cost Effective Foundations are Key to Success

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Housing on GI – Urban Tree, India
Project Background

• Project : INFINITY, Porur
• Location : Porur Gardens, Chennai
• Building : Stilt + 4 floors
• Total flats: 198 units
• Raft Area : 5600 sq.m
• Plot Area : 2.5 Acres (~100m x 100m)

Soil Data and Loading Conditions

Soil Data
• 4 Boreholes were explored to a depth of 20m to 25m below EGL and Uniform Soil Conditions through out the site
• Top 6m : Silty sandy CLAY with 20 to 40% fines
• Below 6m : Medium dense SAND up to 12m, followed firm to stiff silty CLAY up to explored depth
• GWT was at 3m below EGL during investigation (Sep 2012)

Loading Conditions
• Foundation type : Raft
• Loading Intensity : 100 kPa
• Settlement criteria : < 100 mm
Optimal Solution with Savings in Time

Confirming Design by the Developer:
- Driven Cast In-Situ Piles: (5000mm dia. 24m depth, 800 nos.)
- Construction Time: 8 months
- Foundation Cost: INR 45 mio. (Piling + Pile Caps + Others)

Alternative Design by Keller:
- GI Technique: Vibro Stone Columns (dry bottom feed technique)
- Dia. & Pattern: 900mm dia. 1.7m to 1.9m c/c, 6m depth, 5,600 sqm
- Construction Time: 2 months
- Foundation Cost: INR 45 mio. (GI + Granular Blanket + Raft Foundation)

Advantages to the Investor:
- No Savings in Cost
- Savings in Time for about 6 months
- Reduced Carbon footprint
- Locally available stone material (avoided usage of large quantity of cement and steel)
- Early Completion of Project (benefit to Investor by Saving site OH + benefit to Banker by early disbursement of Loans => Early completion and delivered to End User)

Proposed Ground Improvement Scheme

Vibro Stone Columns with Dry Bottom Feed Technique
- Column diameter = 900mm
- Grid pattern = Square grid
- Column spacing = 1.7m & 1.9m
- Treatment depth = 6m below EGL
- Area replacement = 18% to 22%
Monitoring of Settlements

- To check post treatment performance of ground
- Established 14 settlement monitoring points
- Regular monitoring of vertical movement of raft foundation

<table>
<thead>
<tr>
<th>Monitoring points</th>
<th>Construction Status</th>
<th>Equivalent loading (kPa)</th>
<th>Settlement obtained (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1S1</td>
<td>4th Floor Completed</td>
<td>75</td>
<td>&lt; 20</td>
</tr>
<tr>
<td>P1S2</td>
<td>4th Floor Completed</td>
<td>75</td>
<td>&lt; 20</td>
</tr>
</tbody>
</table>

Pour 2: P2S1 & P2S2
Load vs Time Curve
Settlement vs Time Curve
Completed Structure

Design & Build Expertise: Innovative Technology

- Innovative Technology
- Alternative Design & Build Solutions
- Liquefaction Mitigation
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Industrial Plant @ Singapore
Industrial Plant @ Hajipir
Multi-storeyed tower @ NCR
Residential building @ Chennai
Wind Turbines @ Kolhapur
### About the Project

- **Project Location**: Bhendewadi, Kolhapur, Maharashtra
- **Client**: Gamesa (100% subsidiary of Gamesa Spain)
- **Wind Turbines**: 58 Locations  
  25 (locations) for ground improvement
- **Type & Height**: G58 & 65m
- **Capacity**: 850 kW
- **Foundation Size**: 10.2m x 10.2m x 1.1m @ 2.1m below GL

### Static Loads
- **Self weight of turbine**: 150 T
- **Self weight of foundation**: 300 T

### Geotechnical Challenges
- Achieving required Bearing Capacity
- Satisfying ‘Rotational Stiffness’ requirements
- Working in high altitudes

### Typical Wind Mill
Site Layout

Subsoil Data (Typical)

Elevation [m]

Standard Penetration Test, SPT N [ ]
Typical Scheme & Activities

Installed Wind Mills
Load Test (Satisfying Rotational Stiffness)

- Load Intensity \( = 200 \text{ KPa} \)
- Depth of fdn, \( D_f = 2.1 \text{m} \)
- Size of fdn, \( B = 10.2 \text{m} \)
- \( P \), applied load \( = 200 \text{ KPa} \)
- \( w \), obs settlement \( = 3.05 \text{mm} \)
- \( \mu \), Poisson’s ratio \( = 0.33 \)
- \( G \) \( = E_s/2(1+\mu) \)
- Estimated \( K_{R, PLT} \) > Required \( K_R \)

Rotational Stiffness

1. Typical Load Test Graph
2. Determination of \( E_s = E_s, \text{stat} \) from the slope of the curve till elastic limit.
3. \( E_s = (\pi/4)(p/w)*D'(1-\mu^2) \)
4. Rotational Stiffness

\[
K_R = \frac{BG R^2}{3(1-v)} \left(1 + \frac{R}{6H_D} \right) \left(1 + 2 \frac{D_f}{R} \right) \left(1 + 0.7 \frac{D_f}{H_D} \right)
\]

.....DNV/RISO
Concluding Remarks: Technical & Design Expertise

1. Ground improvement techniques such as Dry Vibro Stone Columns, Deep Soil Mixing, Jet Grouting, Prefabricated Vertical Drains can be used to provide Optimal Foundations.

2. These techniques can be used both for heavy, tall & settlement sensitive structures and also for smaller simpler structures.

3. Optimal Foundations offer savings in cost, time, materials, convenience and protection to the environment.

4. Excellent soil information, a correct choice of technique, good equipment, experienced people, testing and monitoring during and after construction is essential for successful project completion.

Operational Excellence: Bored Piling Experience

Execution Challenges (BCIS Piles)
- Borehole Stability
- Knowledge on Drilling Fluid
- Effective usage of stabilizing fluid
- Operational Efficiency
- Quality Control

Metro Rail Project @ Kochi
Kochi Metro Rail Project

**Project**: About 25 km long Elevated Metro Rail Project
**Location**: Cochin, Kerala State
**Structure**: Piers and elevated corridor
**Construction Site**: Within City Environment

**Execution Challenges**

1. **Busy Traffic**
2. **Congested Roads and Limited Working Place**
3. **Limited working hours**
4. **Presence of Live Utilities**
5. **Weak soils up to 50m depth**
6. **Large diameter piles (1.0m, 1.2m & 1.5m)**
7. **Pile lengths 40m to 56m**
8. **Maneuvering of heavy equipment in the limited working place**

**Pile Bore Stability**
When Pile Bore Collapse happen.....?

- During boring operation
- Just before pouring of concrete
- During pile concrete operation

**Reasons for Collapse of Pile Bore**

- Loose soil deposits
- Water table
- Vibrations or earthquake effects
- Height of unsupported face of the pile bore
- Poor knowledge on drilling fluid
- Drilling fluid level inside the pile bore

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**Typical soil profile for Kadavanthra Station**

- *Design Profile*
  - 0 m: Road Strata
  - 3 m: Soft clay
  - 6 m: Stiff to firm Clay
  - 14 m: Loose sand
  - 16 m: Hard Clay
  - 25 m: Weathered Rock
  - 42 m: BH Termination level
  - 50 m: Ver Dense Sand

**Stable Pile Bore**

- Polymer or Bentonite enables for the application of hydrostatic pressure against the sides of the pile by creating a bridging effect:

**Un-stable Pile Bore**

- If top level of Polymer or Bentonite drop below ground water table, the pile will collapse.
### Borehole Collapse (typ)

![Borehole Collapse Image]

### Properties of Drilling Fluid: Bentonite

<table>
<thead>
<tr>
<th>Property to be Measured</th>
<th>Test and apparatus</th>
<th>Fresh Bentonite</th>
<th>During Excavation</th>
<th>Prior to Concreting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>Mud balance</td>
<td>1.015 to 1.06</td>
<td>1.015 to 1.3</td>
<td>&lt; 1.20</td>
</tr>
<tr>
<td>Viscosity</td>
<td>Marsh cone method</td>
<td>&gt;30 sec</td>
<td>32 to 65</td>
<td>N.A.</td>
</tr>
<tr>
<td>pH</td>
<td>pH indicator</td>
<td>8 to 12</td>
<td>6.5 to 12</td>
<td>N.A.</td>
</tr>
<tr>
<td>Sand Content</td>
<td>Sand Content Kit</td>
<td>NA</td>
<td>&lt;25%</td>
<td>&lt;4%</td>
</tr>
<tr>
<td>Frequency</td>
<td>-</td>
<td>After Mixing</td>
<td>Once per shift</td>
<td>Prior to concreting</td>
</tr>
</tbody>
</table>
Boring of Deep Pile using Bentonite

Bentonite Tanks Set-up (Manorama Jn.)
Bentonite Tanks Set-up (Manorama Jn.)

Bentonite Tanks Set-up with De-Sander
Bentonite Tanks Set-up with De-Sander (Typ)

Piling Site using Bentonite
Introduction to Polymer

Advantages of Polymer over Bentonite

- Operational convenience
  - Lesser plant
  - Lesser activities
  - Reduced time
  - Easy Disposal

- Technical advantages
- Environmental friendly

Experience on Polymer usage

1. Preparation
   Can be used immediately after mixing. Unlike Bentonite which requires 24 hours advanced mixing for full hydration.

2. Work
   For bentonite desanding is required to reduce the sand content prior to re-use after return from pile hole. Polymer do not require desanding.

3. Cost
   Unwanted mud from the desanding process needs to be treated properly and taken to a landfill to dispose. The cost is high.

4. Pile Capacity
   Pile installed using polymer get better skin friction than the pile installed using bentonite.
Facts of usage of Polymer

Important note when using Polymer to stabilize the pile hole:

Note 1:
Study the bore hole carefully. Make sure that there is no loose sand or running sand. These loose sand layer must be seal off by temporary casing. If these loose sand layer cannot be sealed off by temporary casing, do not use polymer. Switch to use Bentonite.

Note 2:
Set up the Silo, square tank and mixer based on standard layout. Always make provisions to switch to Bentonite in case the soil report are inaccurate. There may be loose sand at depths which is difficult to be sealed off by temporary casing. Always make provision to add desander.

Note 3:
FOR THE PURPOSE OF PREVENTING COLLAPSE, BENTONITE IS BETTER THAN POLYMER.

Properties of Drilling Fluid: Polymer

<table>
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<th>During Excavation</th>
<th>Prior to Concreting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Viscosity</td>
<td>Marsh Cone Method</td>
<td>32 – 60 sec</td>
<td>40 – 60 sec</td>
<td>N.A</td>
</tr>
<tr>
<td>Density</td>
<td>Mud balance</td>
<td>1.02 to 1.06</td>
<td>1.02 to 1.15</td>
<td>&lt; 1.25</td>
</tr>
<tr>
<td>pH</td>
<td>pH indicator</td>
<td>8 to 12</td>
<td>8 to 12</td>
<td>N.A</td>
</tr>
<tr>
<td>Sand Content</td>
<td>Sand Content Kit</td>
<td>N.A</td>
<td>N.A</td>
<td>&lt; 4 %</td>
</tr>
</tbody>
</table>
Polymer Mixing Flow Diagram

Mixing Plant & Silos (Singapore)
Mixing Plant & Tanks (India)

Boring Operation using Polymer
Kochi Metro (Polymer Bund Set up)

Mixing Plant & Tanks (Kochi)
Kochi Metro (Polymer Bund Set up)

Kochi Metro (bottom cleaning)
Key Factor: **Reliable Soil Investigation…..!!!!!**

- Reliable soil data is must to **OPTIMIZE** appropriate foundation alternatives
- Advanced investigation techniques such as **ECPTs** shall be adopted to obtain relevant soil data over the project area along with **few confirmatory BHs**

![Graph Image](image)

**Cost Effective Alternate Solutions**

- Choice of foundation technique to suit the project specifications
  - Heavy Foundations such as **BCIS Piles**
  - Shallow Foundations (**Innovative technologies** to suit the project boundary conditions e.g. **dry VR Techniques** using bottom-feed method)
  - **Appropriate GI techniques** shall be adopted for Earthquake Prone Regions (Liquefaction Mitigation)
  - **Reliable Soil Investigation + Design + Testing**
  - Seepage Control Measures (**Grouting Techniques**)
  - Strut-free Excavation Supporting System (**Ground Anchors**)
Summary

- **Technical Expertise** will play an important role in execution of foundations (esp. for Deep Bored Piles).

- Execution of Deep Bored Piles requires state-of-the-art process. **Operational Excellence** with best practices deliverers the high quality whilst ensuring peak productivity.

- International standard of practices using latest equipment ensures the required **Speed of Execution** beneficial for early completion of project.

- **Design & Build** Expertise will ensure savings in Cost & Time for the investor. Also ensures, implementation of latest techniques in foundation construction.

- **Safety** goal of zero accidents is possible with dedicated safety systems and motivated leadership.

Thank you for your attention………

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Bored Cast In-Situ Pile Foundations