c. Heavy Tamping and Dynamic Consolidation
(Dynamic compaction)

- Dynamic compaction involves lifting and dropping a heavy weight several times in one place. The process is repeated on a grid pattern across the site.

- For over 15 years this process has been used to achieve ground compaction and consolidation to considerable depths providing a suitable base on which to support structures.

- A solid steel tamping weight is dropped onto the ground from a sufficiently great height to achieve the necessary compaction.

- The resulting high energy impact transmits shock waves through the ground to the depth to be treated.

- This reduces air and water voids between soil particles resulting in enforced settlement.
Overlapping imprints ensure uniform compaction.

Size of tamper and the height of drop determine the depth of treatment.
• The treatment is carried out in a series of impact positions on various grid patterns which are arranged so that compacted zones beneath the weights overlap to ensure the whole area has been treated.

• Thus, foundation loads will be supported without shear failure or excessive settlement.

• Typically, the weights vary from 8 to 20 tonnes and the height of drop between 2 and 25 metres.

Masses up to 190 tonnes and drops of 25m are used by TLM (Technique Louis Ménard) in France.

• It is necessary to use specially adopted crawler cranes having lifting capacities of 50-150 tonnes.

• Heights and number of drops are varied according to site conditions.
• A wide range of free draining granular soils can be treated embracing many natural deposits and fills including hydraulically dredged sand, domestic and industrial refuse.

• However, it is impossible to improve soft saturated or sensitive clays.

• Effective for compacting loose sand but not clay.

Heavy compaction tends to annoy the neighbours, which limits its use in built-up areas.
Compactive energy per blow = \( m \cdot g \cdot h \)

where

\( m \) = mass of the falling weight in metric tons,

\( g \) = gravitational constant,

\( h \) = height of fall in meters.

Estimated depth of compaction,

\[ D = n \cdot \sqrt{(m \cdot h)} \]

where

\( n \) is an empirical constant between 0.3 and 1,

depending on the grain size distribution and degree of saturation

- 0.5-1 for sands,
- 0.3-0.5 for silts and clayey soils.
d. Vibrocompaction and Vibroreplacement

Compaction by insertion of a cylindrical vibrating probe into the ground.

- **Vibrocompaction** – Granular material is added as the probe is removed from the ground.

- **Vibroreplacement** – A “stone column” is built with coarse material that replaces the natural ground.
The installation procedure of a Vibro Compaction

- **Penetration**
  The vibroprobe penetrates to the required depth by vibration and jetting action of water and/or air.

- **Compaction**
  The vibroprobe is pulled out from the maximum depth in 0.5 m intervals. The in situ sand or gravel is flowing towards the vibroprobe.

- **Backfill**
  The compaction is achieved either with backfill from the top or with in situ soil only.
Diagram 1. Suspended by a crane or other support, the Vibroflot is positioned above the selected point. With the aid of the lower water jets and its own weight, the Vibroflot penetrates to the desired depth. When this has been reached these jets are turned off.

Diagram 2. Water flow is switched to the upper jets, and compaction begins. Vibration rearranges the grains around the vibrating head. To compensate for increased density, sand or gravel is added from the top. The flow of water assists the feed of fill material.

Diagram 3. The Vibroflot is raised step by step, forming a compacted cylinder 2 to 4 metres in diameter. Compaction points are arranged so that the areas of influence overlap. Thus a deep raft of treated ground, having uniform density, is formed.

- Both vibro-compaction and vibro-replacement use a *vibrating poker* to make a hole in the ground.

- Vibro-compaction (Vibroflotation) involves the use of a vibrating probe that can penetrate granular soil to depths of over 30 m.

The vibrations of the probe cause the *grain structure to collapse* thereby densifying the soil surrounding the probe.
• Vibro Compaction (also known as "Vibroflotation") is used to compact loose granular soils to a depth of up to 58 m (190 ft) (world record).

• In recent years the method has boomed in Asia for the compaction of large land reclamations like the Chek Lap Kok Airport in Hong Kong.

Vibroflotation method of operation is used with non-cohesive soils such as sand or gravel.

Compaction occurs by simultaneous vibration and saturation.
Vibro Compaction

Objectives

• Increase bearing capacity and reduce foundation size

• Reduce foundation settlement

• Mitigate liquefaction potential

• Permit construction on granular fills

Benefits of Vibro Compaction:

• Cost & Schedule Savings:

The performance of installation of a Vibro Compaction is very high compared to any other soil improvement system.

• Environmental:

Soils can be compacted in-situ without the need of their removal and replacement by better material. Vibro Compaction can be safely operated near existing structures. Other than Dynamic Compaction
The compaction points are arranged in an equal sided triangular grid of typically 2.5 m to 4.5 m spacing.

The zone of compaction (influence) around a single probe will vary according to the type of vibroflot used. The cylindrical zone of compaction will have a radius of about 2m for a 30-hp unit. This radius may extend to about 3m for a 100-hp unit.

The detailed spacing is either selected by

- the specialist contractor or,
- in larger jobs, determined in a testing field in which several spacings and pulling criteria are tried out.

### Examples of Vibroflotation Patterns and Spacings for Footings

<table>
<thead>
<tr>
<th>Square Footing (size - ft)</th>
<th>Number of Vibroflotation Points</th>
<th>C-C Spacing (feet)</th>
<th>Pattern</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;4</td>
<td>1</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>4.5 - 5.5</td>
<td>2</td>
<td>6</td>
<td>Line</td>
</tr>
<tr>
<td>6 - 7</td>
<td>3</td>
<td>7.5</td>
<td>Triangle</td>
</tr>
<tr>
<td>7.5 - 9.5</td>
<td>4</td>
<td>6</td>
<td>Square</td>
</tr>
<tr>
<td>10 - 11.5</td>
<td>5</td>
<td>7.5</td>
<td>Square plus one @ center</td>
</tr>
</tbody>
</table>
The quality of the compaction can be checked by

- CPT tests,
- SPT tests or

more directly through the measurement of the change in in-situ bulk density of the compacted soil (however, it is difficult to achieve undisturbed sampling in sands and gravels).
Important indications for a well going compaction are:

- the ground settlement and
- backfill consumption during installation and
- the amperage increase of the vibroprobe's motor in each compaction interval.

Disadvantages

Vibro Compaction cannot compact soils with more than 12 % to 15 % fines content.

Vibro Compaction requires a minimum vertical stress in the soil in order to be effective, which means that in the upper 90 cm from the surface there is no improvement so this surface layer has to be roller compacted.
Zone A: Excellent for densification; however if gravel content exceeds 20%, depth may be limited to 10 m.
Zone B: Best
Zone C: Fines may hinder densification. Better to use vibroreplacement

Effectiveness

<table>
<thead>
<tr>
<th>Ground Type</th>
<th>Relative Effectiveness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sands</td>
<td>Excellent</td>
</tr>
<tr>
<td>Silty Sands</td>
<td>Marginal to Good</td>
</tr>
<tr>
<td>Silts</td>
<td>Poor</td>
</tr>
<tr>
<td>Clays</td>
<td>Not Applicable</td>
</tr>
<tr>
<td>Mine Spoils</td>
<td>Good (if clean granular)</td>
</tr>
<tr>
<td>Dumped Fill</td>
<td>Dependent On Nature of Fill</td>
</tr>
<tr>
<td>Garbage</td>
<td>Not Applicable</td>
</tr>
</tbody>
</table>

Fig. 3.4 Range of Soils Suitable for Improvement by Vibroflotation (Glover, 1982)
Backfill selection

The grain size distribution of the backfill material is one of the factors that control the rate of densification. Brown (1977) has defined a **suitability number**, $S_N$, for rating a backfill material.

\[
S_N = 1.7 \sqrt{\frac{3}{D_{50}^2} + \frac{1}{D_{20}^2} + \frac{1}{D_{10}^2}}
\]

$D_x$; Particle diameter corresponding to $x$ % finer (in mm)

0 – 10  Excellent
10 – 20  Good
20 – 30  Fair
30 – 50  Poor
> 50     Not Acceptable

The Stone Column method (Vibroreplacement stone columns)

This mode of operation is used with cohesive, impermeable soils such as silts or clays

in which intergranular cohesion makes grain redistribution impractical and low permeability prevents the necessary rapid dissipation of pore water.
Vibro Replacement

Vibro Replacement is a combination of vibroflotation with a gravel backfill resulting in stone columns, which not only increases the amount of densification, but provides

• a degree of reinforcement and
• a potentially effective means of drainage.

Diagram 4. The soil is penetrated to the required depth by the combined effect of Vibroflot weight, vibration and jetting action by air and/or water. If only air is used, the in-situ soil is displaced sideways. Using water only, disturbed material is also flushed from the hole.

Diagram 5. The Vibroflot is then lifted out. Coarse gravel, crushed stone or slag is tipped into the hole in increments of about 500mm. The Vibroflot is re-inserted and compaction begins. Radial forces produced by the vibrator force the added material horizontally out against the in-situ soil.

Diagram 6. When the required degree of compaction has been reached the Vibroflot is again removed. The filling/compacting cycle is repeated step by step to the surface. Thus, a dense column of granular material interlocking with the surrounding ground is formed through the treatment zone.
**Objectives**

- Reduce foundation settlement
- Increase bearing capacity, allowing reduction in footing size
- Mitigate liquefaction potential
- Provide slope stabilization
- Permit construction on fills
- Permit shallow footing construction
- Prevents earthquake-induced lateral spreading
Vibroreplacement Stone Columns
This schematic shows the various steps in the vibroreplacement process. First, the vibroflot penetrates the ground to the desired depth. Stone is then progressively introduced to the hole, and the vibroflot is alternately raised and lowered to produce a packed stone column.
Typical Parameters

• Column diameter: 0.6 to 1.0 m
• Gravel particles: 20 – 25 mm
• Spacing: 1.5 to 3.5 m

Vibro Replacement stone columns

• The purpose of the stone columns is to reduce the potential for liquefaction of the subsurface soils during an earthquake.

• Vibroreplacement stone columns improve the resistance of cohesionless soils to liquefaction by several mechanisms.
• The primary mechanism of treatment is the densification of the native soil.

• Secondary benefits may also come from the reinforcing effects of the stone columns (e.g., they are usually stiffer than the surrounding soil),

an increase in the in-situ horizontal stress (e.g., due to the packing of stone in the column),

and the drainage of earthquake-induced pore water pressures through the stone columns.

e. Compaction Grouting

Vibro replacement with the addition of stabilizing agents is more appropriately classified as compaction grouting.

Such construction methods include:

• Mortared stone columns formed by injecting mortar into a stone column

• Concrete vibro-columns, created by pumping concrete into ground cavities created by a vibrator.