Some Environmental Benefits of Dry Vibro Stone Columns in a Gas Based Power Plant Project

Chawla, G.R.  Raju, V.R.¹  Krishna, Y.H.¹
General Manager  Managing Director  General Manager
North Delhi Power Limited, New Delhi  Keller Ground Engineering India Pvt. Ltd., New Delhi
¹Keller Ground Engineering India Pvt. Ltd., New Delhi

ABSTRACT

Dry Bottom Feed Vibro Displacement was adopted in a Gas Based Power Plant of North Delhi Power Limited (NDPL), New Delhi to support ancillary structures in a seismically active zone. The technique delivered required bearing capacity to the structures whilst reducing the post construction settlements. In addition, the foundation system is designed to mitigate the risk of liquefaction potential in the event of an earthquake. This paper discusses the details of design, execution, quality control, testing and environmental benefits in terms of embodied CO₂ for Dry Vibro Displacement technique adopted at NDPL project.

1. INTRODUCTION

The construction industry as a percentage of India’s GDP has been around 10% in past few years. The present Government initiatives and budget allocation indicates that the generation of power has become a very important concern. A number of power plants are coming up even in congested cities and seismic active zones. Hence, the design of such facilities has to be robust enough for safe functioning even during an event of earthquake (and allied phenomena like liquefaction). Another interesting development is the increasing consciousness of the need for construction activities to be more environmentally sustainable. The foundation system adopted in a 108 MW Gas Based combined cycle power generating facility of North Delhi Power Limited (NDPL) located in Rithala, New Delhi is an example of a technically sound and environmentally friendlier solution, where ground improvement was chosen over Bored cast-in-situ piling for some of the structures. This power generating facility has structures like Switchyard, Water cooling system, Power plant block, Gas Compressor plant, clariflocculator etc.

Dry Vibro stone columns were adopted instead of Bored cast-in-situ piles to support ancillary structures of power plant situated in a seismically active zone. Dry Vibro Stone Columns were selected primarily because of efficiency in liquefaction mitigation. However, an additional benefit was that the Vibro stone column solution was more environmentally friendly.

2. SUBSURFACE CONDITION

The site in general consists of loose to medium dense sandy soils with SPT N values ranging between 5 and 20 to a depth of about 10 to 12m. This is followed by dense silty sands / sandy silt (N> 15 to 30) to about 30m. The borehole information is summarized in Table 1.

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Depth, m</th>
<th>Soil Description</th>
<th>SPT N Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0-1</td>
<td>Fill</td>
<td>5 to 10</td>
</tr>
<tr>
<td>2</td>
<td>1-4</td>
<td>Sandy silt</td>
<td>10 to 20</td>
</tr>
<tr>
<td>3</td>
<td>4-10</td>
<td>Silty fine sand</td>
<td>4 to 13</td>
</tr>
<tr>
<td>4</td>
<td>10-30</td>
<td>Sandy silt</td>
<td>&gt; 30</td>
</tr>
</tbody>
</table>

Ground water table at 5 to 6m below GL

This site falls under Zone IV according to Indian Seismic Code (IS 1893: 2002), with a design peak ground acceleration of 0.24g. The presence of loose silty fine sand and a PGA of 0.24g indicate the possibility of liquefaction in an event of earthquake.

3. FOUNDATION SELECTION

The gas based power plant at NDPL, Rithala, New Delhi included many heavy structures like Transformer building, Turbine building etc. and lighter ancillary structures (loading intensity < 150 kPa) like clariflocculator, tank structures and other auxiliary buildings. Tall and heavy structures were founded on bored cast-in-situ piles to take heavy vertical and earthquake-induced lateral loads. However for structures
with light to medium loads (load intensity ~ 150 kPa), Vibro stone columns were selected. Vibro stone columns can be designed to prevent liquefaction during a seismic event (Priebe, 1998). The following were the design objectives:

• To provide adequate bearing capacity
• To mitigate liquefaction potential of soil
• To limit the settlements of the structure

For the selected structures, Vibro stone columns had the following advantages over the confirming Bored cast-in-situ Piles foundation:

• Savings in cost
• Savings in construction time
• More environment friendly

The chosen dry method of installation (Bottom feed) method did not require water for penetration, relieving the site team of the need to handle and dispose large quantities of muck. It is also well suited for a congested site, with many simultaneous activities.

4. STONE COLUMN ANALYSIS & DESIGN

The design criterion of Ground Improvement was to prevent liquefaction in an event of earthquake with PGA of up to 0.24g. The liquefaction potential of the in-situ soil was calculated as per Seed & Idriss (1971) and the same was calculated according to Priebe (1998) for the improved ground. The stone columns were designed with 0.5m diameter installed at a distance of 2m centre to centre in triangular grid pattern. Depth of stone columns varied from 8m to 12m depending on the liquefiable zone.

Figure 1 illustrates the SPT N values required to resist liquefaction, varying with depth. Vibro stone columns reinforce the in-situ soil, and also provide a drainage path for the dissipation of excess pore pressures. As a result of these beneficial effects, the SPT N values in the in-situ soil required to resist liquefaction comes down. In addition, the installation of the columns densifies the in-situ soil, because of the displacement effect, as well as densification by vibrations.

5. INSTALLATION METHOD

Stone columns were installed using the Dry bottom-feed method of installation. For this method of installation, a rig called a Vibrocat is used. It consists of a bottom-feed depth vibrator mounted on a crawler-rig. An operational advantage of the Vibrocat is that it is able to exert a pull-down force, improving penetration speed and hence productivity. A typical Vibrocat unit, used on site, is shown in Figure 2.

Figure 2: Typical Vibrocat Unit Being Charged with Stones Using a Loader

The Vibrocat feeds the coarse granular material to the tip of the vibrator with the aid of pressurized air. The installation method consists of alternative steps of penetration and retraction. During the retraction, gravel runs from the vibrator tip into the annular space created and are then compacted using vibrator thrusts and compressed air. Figure 3 illustrates the schematic of this process.

Over 1,700 nos. of stone columns were installed to support 12 ancillary structures in power plant, treating a
6. PERFORMANCE ASSESSMENT

During installation, quality control for all the stone columns was done by monitoring the following parameters, using a real-time monitoring system:

- Depth of stone column
- Volume of stone placed
- Current drawn from the vibrator power source (compaction effort)

For more details of quality control during Vibro stone column works, the reader is referred to Raju & Sondermann (2005).

In addition to the above installation inspections, a plate load test was conducted to estimate settlement characteristics under maximum design load. The single column plate load test was conducted on the installed Dry Vibro stone column with a maximum test load of 113 T on a test plate of 1.5m x 1.5m (i.e., load intensity ~50 T/m²). The load vs settlement plot for the load test is shown in Figure 4.

![Fig. 4: Load vs Settlement for a Single Column Load Test](image)

7. ENVIRONMENTAL BENEFITS

In general, the following are some environmental benefits of dry Vibro stone columns over Bored cast-in-situ pile:

- The overall stone columns solution consumes less fuel
- Stone column installation using Dry Vibro (Bottom feed) method works by displacement method and hence there is little or no handling and disposal of waste soil
- The ground improvement method using stone columns, allows the site to be easily reused in the future, by not leaving any obstructions in the ground

While not done so in this project, recycled stones can be used in Vibro stone columns, without compromising technical performance.

However, for a quantitative comparison of environmental benefits of the alternate foundation system, a comparison of embodied CO₂ can made between the Vibro stone columns and the original foundation system – Bored cast-in-situ piling. The concept of embodied CO₂ is useful as it provides an indication of the amount of Green House Gases (GHG) emitted by a particular activity of production process (Egan et al., 2009). The embodied CO₂ is defined as the CO₂ that is emitted by burning fossil fuels during the manufacture and transport, as well as the CO₂ emitted through chemical processes, such as when manufacturing cement.

**Embodied CO₂ Calculation**

The quantities of the bored pile foundation scheme (conforming design) and the Vibro stone columns (alternative design) are given in Table 2.

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Item</th>
<th>BCIS Piles</th>
<th>Stone Columns</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>No. of piles / columns</td>
<td>379</td>
<td>1,800</td>
</tr>
<tr>
<td>2</td>
<td>Diameter [m]</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>3</td>
<td>Depth [m]</td>
<td>25</td>
<td>10</td>
</tr>
<tr>
<td>4</td>
<td>Linear meter [m]</td>
<td>9,475</td>
<td>18,000</td>
</tr>
</tbody>
</table>

The basis of calculation is as follows:

- Embodied CO₂ of all the major materials used for construction are considered for calculation
- Embodied CO₂ of fuels used for installation of foundation system is considered
- Fuel consumption of Dry Vibro Stone Column (bottom feed) installation is considered as 2.5 litres per meter of installation
- Fuel consumption of bored cast-in-situ piling works is considered as 8 litres per meter of installation (this included the consumption for cage lowering, concreting, etc)
- Fuel consumption of water pump which is required for bored cast-in-situ piling works is negligible and hence not considered
- Embodied CO₂ due to transportation of materials is ignored in both the case
- A wastage of 15% and 20% is considered for concrete and stone during installation of BCIS Piles and stone columns respectively

The values of embodied CO₂ considered for different materials are shown in Table 3.

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Item</th>
<th>Embodied Carbon</th>
<th>Ref.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Concrete</td>
<td>0.130 kg CO₂/kg</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Stone aggregate</td>
<td>0.005 kg CO₂/kg</td>
<td>[5]</td>
</tr>
<tr>
<td>3</td>
<td>Reinforcement Steel</td>
<td>1.770 kg CO₂/kg</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Fuel - Diesel</td>
<td>3.180 kg CO₂/kg</td>
<td>[2]</td>
</tr>
</tbody>
</table>
The consumption of materials for the two foundation systems is given in Table 4.

**Table 4: Material Consumption**

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Item</th>
<th>BCIS Piles</th>
<th>Stone Columns</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Concrete (incl. wastage)</td>
<td>5135 T</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>Stone aggregates (incl. wastage)</td>
<td>-</td>
<td>8482 T</td>
</tr>
<tr>
<td>3</td>
<td>Reinforcement Steel</td>
<td>216 T</td>
<td>-</td>
</tr>
<tr>
<td>4</td>
<td>Fuel consumption for installation*</td>
<td>75,800 lit</td>
<td>45,000 lit</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(62,914 kg)</td>
<td>(37,350 kg)</td>
</tr>
</tbody>
</table>

* Diesel density is considered as 0.83 kg / litre

Table 5 compares the breakdown of embodied CO$_2$ of BCIS Piles and Vibro Stone columns for this particular case study. It illustrates that the embodied CO$_2$ of installation of Bored cast-in-situ piles for the ancillary structures is around 1,250 T whereas embodied carbon of equivalent foundation system by Dry Vibro Stone Columns is around 160T, i.e., ~87% less emission than BCIS Piles.

**Table 5: Embodied Carbon Comparison**

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Item</th>
<th>Embodied CO$_2$ [kg]</th>
<th>BCIS Piles</th>
<th>Stone Columns</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Concrete (incl. wastage)</td>
<td>667,516</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Stone aggregates (incl. wastage)</td>
<td>-</td>
<td>42,412</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Reinforcement Steel</td>
<td>382,373</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Fuel consumption for installation*</td>
<td>199,354</td>
<td>118,350</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(1,249 T)</td>
<td>(161 T)</td>
<td></td>
</tr>
</tbody>
</table>

**REFERENCES**

Carbon calculator for construction activities V.3.1.1 (http://www.bath.ac.uk/mech-eng/embodied, retrieved 26th April, 2010), Environmental Agency, UK
Keoleian, G.A. Life cycle design. School of Natural Resources and Environment, University of Michigan.

8. CONCLUSION

The use of dry Vibro stone columns in this project provided a satisfactory foundation system that not only met the structural and geotechnical design criteria, but also demonstrated benefits from a cost and schedule stand point. It was shown that stone columns can improve the loose to medium dense silty sand sufficiently to support loads up to 150 kPa. Post treatment plate load tests gives settlements less than 16mm even at load intensity of 500 kPa.

In addition to the technical performance and commercial benefits, an embodied CO$_2$ calculation showed an environmental benefit (lower greenhouse gas emissions) of the Vibro stone column solution.