FOUNDATIONS FOR RETAINING WALLS ON SOFT CLAY DEPOSITS ALONG HIGHWAY TO ICTT, VALLARPADAM PORT IN COCHIN

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ABSTRACT: The paper presents case history of ground improvement using stone columns for foundations of retaining walls in a stretch of highway connecting ICTT Vallarpadam with NH 47. The land width was inadequate to cater for 8m height embankment with side slopes. Subsoil being soft clay / silty clay of upto 12m depth, 1m dia stone columns were installed at a spacing of 1.65m to 2.50m, depending on the height of the retaining wall, for improving the bearing capacity and reducing settlements. Vibroflot stone columns were adopted because of their fast installation rate.

INTRODUCTION
ICTT Vallarpadam is being connected with NH-47 by a nearly 17.00 km long Four Lane Highway. About 10 km of this length is routed across backwaters and rest is on land. In the land area the problems faced by the highway are
a) Limited right of way availability.
b) Subsoil consists of soft /loose soil deposits up to 12.0 m depth.
c) Embankment height is about 8.0 m.

The right of way is inadequate for forming slopes of the fill and steep slopes were found to be unsafe due to soft foundation clay. Hence the fill had to be kept stable by retaining walls at many locations.

The bearing capacity of the subsoil is inadequate to support the load transferred by retaining wall, and a combination of methods were used to ensure adequate bearing capacity. These include
a) Replacement of soft soil below retaining wall with good quality granular material.
b) Ground improvement with stone columns.

Fig 1 Shows Typical cross section of Retaining wall. The embankment height extends up to 8.00m and the height of retaining wall varies from 4.0-8.0m from bottom of foundation. In general, side slope adopted for the embankments was 1V: 2H. Locally available moorum was used as fill material, which has cohesion (c) 3.0 t/m², angle of internal friction (ϕ) 270, dry density (γd) 1.9 t/m³.

Geotechnical Properties of Subsoil
35 boreholes of depth ranging from 10.0m to 30.0m were made in this stretch. Typical geotechnical properties of the subsoil layers in the land area are mentioned in Table 2 (see next page), from which it is clear that the shear strength of soil is very low and the compressibility is very high.

F.O.S of Retaining Wall With No Ground Improvement
The heights of embankments, thickness of soft compressible soil, heights of retaining wall and corresponding bearing capacity, FOS in rotational stability and settlements are given in Table 1 for the case of no ground improvement.

<table>
<thead>
<tr>
<th>Table 1: F.O.S of Retaining Wall with No Ground Improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height of embankment (m)</td>
</tr>
<tr>
<td>Height of RCC Retaining wall from founding level(m)</td>
</tr>
<tr>
<td>Thickness of Soft Compressible Layer (m)</td>
</tr>
<tr>
<td>Safe Load Bearing Capacity of open foundation (t/m²)</td>
</tr>
<tr>
<td>Required Load Bearing Capacity (t/m²)</td>
</tr>
<tr>
<td>F.O.S in rotational stability</td>
</tr>
<tr>
<td>Total Estimated Settlement (mm)</td>
</tr>
</tbody>
</table>

Bearing Capacity of Retaining wall foundation was evaluated as per guidelines given in IS: 6403[1] & IRC: 78[2].
Table 2: Typical geotechnical properties of subsoil layers

<table>
<thead>
<tr>
<th>Layer No</th>
<th>Thickness of Layer (m)</th>
<th>SPT Values</th>
<th>Unit Weight i.e. bulk(t/m³)</th>
<th>Cohesion i.e. c (t/m²)</th>
<th>Angle of Internal Friction, i.e. φ(deg)</th>
<th>Compression Index (Cc)</th>
<th>Recompression Index (Cr)</th>
<th>Initial Void Ratio (e₀)</th>
<th>Coefficient of Consolidation i.e. Cv (m²/day)</th>
<th>Pre-consolidation Pressure i.e. pc (t/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Layer 1</td>
<td>4.2</td>
<td>2</td>
<td>1.70</td>
<td>1.50</td>
<td>0.75</td>
<td>75</td>
<td>0</td>
<td>4</td>
<td>5.00</td>
<td>-</td>
</tr>
<tr>
<td>Layer 2</td>
<td>2.5</td>
<td>4</td>
<td>1.80</td>
<td>2.50</td>
<td>0.45</td>
<td>45</td>
<td>1</td>
<td>4</td>
<td>10.0</td>
<td>-</td>
</tr>
<tr>
<td>Layer 3</td>
<td>2.9</td>
<td>5</td>
<td>1.85</td>
<td>1.30</td>
<td>0.25</td>
<td>25</td>
<td>1</td>
<td>8</td>
<td>15.0</td>
<td>-</td>
</tr>
<tr>
<td>Layer 4</td>
<td>9.9</td>
<td>8</td>
<td>1.95</td>
<td>4.50</td>
<td>0.20</td>
<td>2</td>
<td>8</td>
<td>8</td>
<td>25.0</td>
<td>-</td>
</tr>
<tr>
<td>Layer 5</td>
<td>11.0</td>
<td>18</td>
<td>2</td>
<td>0.00</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Layer 1: Very Soft to Soft Silty Clay
Layer 2: Soft to Medium Stiff Sandy Silty Clay
Layer 3: Loose Clayey Silty Sand
Layer 4: Stiff Lateritic Silty Sandy Clay
Layer 5: Medium Dense to Dense Clayey Silty Sand

Ground treatment with replacement of soft sub soil maximum upto 2.50m thick below the founding level of retaining wall was adopted in view of high ground water table and related excavation problems as well as the position and thickness of soft clay layer.

Vibroflot stone columns were installed below the base of the retaining wall in stretches where the soft clay layer was very deep and the required bearing capacity was not achieved by replacement of soft / loose soil layers.

Load Carrying Capacity of Stone Columns

Detailed design of ground treatment measures by providing stone column was carried out in accordance with “IS 15284 (Part 1): 2003 Design and Construction For Ground Improvement – Guidelines Part 1 Stone Column” [3] & IRC – HRB - Special Reports 13 and 14 dealing with design and construction of embankments on soft ground.[4]

Stone column derives its capacity from the following three mechanisms:
1) Capacity of the stone column resulting from the resistance offered by the surrounding soil against its lateral deformation (bulging / cavity expansion)
2) Capacity of the stone column resulting from increase in resistance offered by the surrounding soil due to surcharge over it.
3) Bearing support provided by the intervening soil between columns.

Safe load bearing capacity of a single stone column is obtained summing the safe load capacities from each of the above mechanisms. For formulae for evaluation of the same, reference may be made to IS 15284 part 1.[3]

Table 3: F.O.S of Retaining wall with Ground Improvement

<table>
<thead>
<tr>
<th>Height of embankment (m)</th>
<th>Height of RCC Retaining wall from founding level(m)</th>
<th>Safe Load Bearing Capacity of treated ground (t/m²)</th>
<th>Required Load Bearing Capacity (t/m²)</th>
<th>F.O.S in rotational stability</th>
<th>Total Estimated Settlement (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.60-8.25</td>
<td>4.00-8.00</td>
<td>9.80-11.20</td>
<td>7.50-11.20</td>
<td>1.24-1.97</td>
<td>69-130</td>
</tr>
</tbody>
</table>

CONSTRUCTION DETAILS

Stone Columns extend to the full depth of very soft/ soft and medium stiff clayey layer, thereby strengthening all the weak strata. Minimum three stone columns in a square pattern have been provided below foundation throughout the length to utilize maximum resistance against bulging within the limited base width. One additional row of stone column on either side, beyond the base width of retaining wall has been provided to ensure the lateral spreading/ distribution of load through the projected portion of granular blanket over the column. For dispersion of applied load from embankment base to the top of stone column and to aid drainage of the pore water, stone columns are topped with a compacted granular blanket of thickness 500-1500 mm.

At 28 locations where retaining walls were built on 1.0m diameter stone columns the spacing of stone column varied from 1.65m-2.50m in rectangular pattern in all the locations.
The spacing of stone column varied as a function of height of retaining wall and cohesion value of sub soil. Design load of single stone column ranged from 22.50 to 49.00 tonne. Depth of installation of stone column varied from 6.00m to 14.00m depending on the thickness of soft clay.

When the designed depth is reached the borehole is cleaned of any loose muck and aggregates are poured down the borehole. The vibrator is slowly withdrawn in steps of 0.7 to 1.0m and stone falls to the tip of vibrator. The vibrator is then lowered back into the borehole between 0.70 to 0.80m with constant water jet at the tip of vibrator thereby creating a 0.2 to 0.3m length of stone column. The action of vibrator presses the stone radially into the surrounding soil and compacts the stone in the vertical direction as well. This procedure is repeated till the desired length of stone column is reached. Total quantity of stone columns installed was about 38,000 running meter.

The crushed stone (gravel) for stone column consists of clean, hard, angular, chemically inert, resistant to breakage and free from organic material, trash, or other deleterious materials and conforming to the gradation given in Table 4. The uniformity co-efficient was greater than 3 and grain size distribution curve showed the material to be well graded. The aggregate crushing value of the stone shall not be more than 30%, impact value not more than 25%.

Table 4 Gradation of Aggregates for Stone Columns

<table>
<thead>
<tr>
<th>Size of Aggregates</th>
<th>% Passing</th>
</tr>
</thead>
<tbody>
<tr>
<td>75 mm (3&quot;)</td>
<td>90-100</td>
</tr>
<tr>
<td>50 mm (2&quot;)</td>
<td>40-90</td>
</tr>
<tr>
<td>20 mm (3/4&quot;)</td>
<td>0-10</td>
</tr>
<tr>
<td>12 mm (1/2&quot;)</td>
<td>0-5</td>
</tr>
</tbody>
</table>

Stone Column Installation By Wet Method

Wet method was used for installation of the stone columns. In this method, high pressure water jets coming out of the tip of vibrator loosen the soil and carry it away and forming the borehole. The oscillating vibrator sinks under its own weight.

Fig. 2 Typical Elevation showing arrangement of Stone columns and granular blanket below retaining wall

Fig. 3 Installation of Stone Column and placing of Granular blanket at the top of stone column.

Fig. 4 Graph showing power consumption with depth

MONITORING

During construction of each stone column, the following details and parameters was recorded and maintained: Location, reference number, diameter and depth (top & bottom elevation) of stone column. Stack measurement of stone used in the works, computation of average quantity of back fill materials consumed per liner metre of the column, vibrator power consumption during penetration of vibrator for boring the hole and during compaction of stone column. Computation of quantity of back fill material helps in determining the diameter of stone column formed during installation. Fig 4 shows vibrator power consumption with respect to depth during compaction of stone column which helps monitoring its degree of compaction.
Section 1 in Fig.4 shows advance of borehole and section 4 shows corresponding power consumed. Section 2 shows the washing of hole by moving the vibrator up and down the hole. There is no variation of power consumed for this process as shown in section 5. Section 3 shows the formation of column and corresponding power consumed is shown in section 6. Section 6 shows more power consumption than section 5 and section 4, this is because more energy is required for compacting stone column. This energy difference indicates that a well compacted stone column has been formed.

LOAD TEST ON STONE COLUMN:
(i) Initial and routine load tests were carried out as per procedure specified in IS 15284 Part 1 [3]. Load tests were carried out on single stone column and group of three stone columns. The load test was accepted if
(ii) 10 to 12 mm settlement at design load for a single column test
(iii) 25 to 30 mm settlement at the design load for a single column group test.

Fig. 5 Load test on Stone Column

Fig. 5 shows the load test carried out on stone column at site.

Fig. 6 shows load test result on a single stone column. The design load of 22.50 tonne was achieved at 11.00 mm settlement. This was within the permissible limits as per IS 15284 (part 1). Post construction settlements in stone column treated area were very low in magnitude.

ADVANTAGES OF USING STONE COLUMN:
Stone columns are a good alternative to pile foundation where soft/loose deposits of soil exist below the subsoil, because:
1. Installation is very quick around 50 nos of stone column as 10 m depth were installed in a day.
2. Cost of construction of stone column is much less as compared to pile foundation.
3. Overall cost of ground improvement reduces as a result.
4. Post installation settlements of stone columns under the design loads were observed to be small and insignificant. Normally no waiting period is adopted and loads are placed shortly after installation of stone columns.

CONCLUSION
Highway embankments of height ranging from 3m to 8m and resting on soft clay layers of 4.00-12.00 m were to be built. Inadequate ROW necessitated that embankment be kept stable using retaining walls. Due to soft clay subsoil, ground improvement was required and the same was effectively provided using vibroflot stone columns.

ACKNOWLEDGEMENTS
The authors thank design and supervision team members of M/s. LEA Associates South Asia Pvt. Ltd. (LASA) for support and encouragement in the preparation of the paper.

REFERENCES
1. IS 6403 (21981), Code of Practice for Determination of Bearing Capacity of Shallow foundations.