Efficacy of Stone Columns in Flyash Area – A Case Study

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Abstract: In the present era of industrial development, power generation needs to be increased many folds to meet our requirements. Many Thermal power plants cater to the needs of power requirements in India. However due to non-availability of sufficient land, power plants are forced to be constructed over the ash ponds. Flyash is prone to erosion and liquefaction due to its silt size particles with no cohesion coupled with medium range of permeability unless suitable remedial measures are taken. A challenging assignment envisaged by suitable treatment to combat the unforeseen damages caused to structures resting over the ashpond of varying depths upto 17.5 below ground level for Coal Handling Plant of Anpara Thermal Power Project (2x500 MW), Stage D project. The cost effective technical proposals were adopted to foundation system to improve its engineering properties and to mitigate the liquefaction phenomenon.

Introduction
A large quantity of pond ash is accumulated in lagoons at different thermal power plants in India. As pond ash does not have the required pozzolanic reactivity due to uncontrolled methods of disposal and storage, it is least suitable for higher order applications. It is reported that most of the ash ponds were filled to their design capacity, which forced the thermal power plants to acquire thousands of hectares of fresh land. So far, 40,000 hectares of precious land is already occupied by the ash ponds. It is opined that, construction of civil engineering structures over the ash ponds with proper ground improvement may be the possible solution. IIT Roorkee has studied the possible liquefaction potential with ground improvement techniques for Anpara thermal power project. This paper presents a case study for the construction of CHP over the ash pond area for a Thermal power plant at Anpara. Stone columns were proposed for ground improvement to increase the safe bearing capacity and reduce the settlements of open foundation system resting over the flyash and to increase the lateral capacity of pile foundations and also to avoid the liquefaction during earth quake in the plant area.

Geotechnical Investigation Results
Based on the necessity and scope of work intended, total 20 numbers of bore holes were proposed for the plant area to obtain the nature of sub-soil profile and engineering/physical properties. The generalised subsurface stratum at the CHP area is as follows.

Stratum 1: Flyash: This layer is met at ground surface and extended up to 3.0 to 17.5 m below existing ground level. The standard penetration resistance value (N) is varying from 3 to 10 with angle of internal friction in between 25 to 29 degrees. The grain size analysis shows the %of sand and silt is varying from 15 to 78% and 85 to 22% respectively.

Stratum 2: Clayey silt: The thickness of this layer is varying from 3.0 to 19 m with low to medium plasticity. The N value is varying from 11 to more than 50 indicating stiff to hard nature.

Stratum 3: Gravelly silty sand: The thickness of this layer is varying from 0.5 to 6 m with medium dense nature. The N value is varying from 30 to more than 100.

Stratum 4: Clayey silt: The thickness of this layer is varying from 0.5 to 2.0 m with very dense nature. The N value is varying from 76 to more than 100. It is existing only in some of the boreholes.

Stratum 5: Highly weathered rock: This stratum exists in a few boreholes at track hopper location and extended up to borehole termination. The degree of weathering decreases with depth and the Rock Quality Designation (RQD) value ranged from 0 to 60%.

Geotechnical Engineering Proposals
Based on site conditions and detailed geotechnical investigation report and technical specifications of the project, 600 mm dia. Bored Cast In-Situ (BCIS) pile foundations are proposed to support all the important
structures and also for the structures net pressure requirement is more than 10 t/m². For all other structures, the required net bearing pressure is less than 10 t/m², stone columns of 900 mm dia. @ 2.0 m c/c in equilateral triangular pattern are proposed. Design calculations for stone columns are made based on IS code² and literature¹, 2. Considering the ash depth of 10 to 13 m below Finished Ground Level (FGL), it is proposed 500 mm dia. stone columns around the BCIS piles to achieve the required lateral capacity and also to avoid the liquefaction during earthquake conditions. Field tests are conducted to verify the pile capacity and also to check the SBC of improved ground with stone columns.

FIELD TEST RESULTS WITH GROUND IMPROVEMENT

Comparison of Dynamic Cone Penetration Test (DCPT) Data Before and After Ground Improvement

It is intended to conduct the dynamic cone penetration tests before and after ground improvement in the plant area to verify the improvement characteristics of flyash at the proposed locations as indicated in the fig.1. Eight DCPT tests are conducted on the existing and on improved soil with 500 mm and 900 mm dia. stone columns and the results are presented as below.

<table>
<thead>
<tr>
<th>DCPT No.</th>
<th>Location</th>
<th>Ground Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>East/West</td>
<td>Flyash</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Improved flyash with 900 mm stone column</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Improved flyash with 500 mm stone column</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Flyash</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Improved flyash with 900 mm stone column</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Improved flyash with 500 mm stone column</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Flyash</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Improved flyash with 900 mm stone column</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Improved flyash with 500 mm stone column</td>
</tr>
</tbody>
</table>

Fig. 1 Location of dynamic cone penetration tests

Fig. 2 Comparison of DCPT results before and after improvement with 900 mm dia. stone columns

Based on the project requirement, two types of foundation systems were proposed in the CHP area.

1. Open foundation with ground improvement
2. Pile foundations with ground improvement

Open foundation with ground improvement

Open foundations with stone columns are provided for the structures which can be accommodated with in the structural pressure of 10 t/m². To assess the improvement characteristics of flyash, it was proposed to carry out the field tests on single and group columns as per IS 15284, Part-1, with 900 mm dia. stone columns at 2.0 m c/c in equilateral triangular pattern with an embedment of 500 mm in the underlying virgin soil.

Initial stone column tests on single column (ISC-1 & ISC-3) and group columns (ISC-2 & ISC-4) as shown in Fig.4 are conducted at different locations (D1 & D2) and the test results are presented below.

Fig. 3 Comparison of DCPT results before and after improvement with 500 mm dia. stone columns

Fig. 4 Initial stone column test at D1 & D2

The load tests on 900 mm. dia. stone columns are conducted for a maximum test load of 52T (max. load intensity of 15 t/m²) which is 1.5 times the design load of 35T (design load intensity of 10 t/m²) and for three stone column group for a maximum test load of 125T (max. load intensity of 15 t/m²) which is 1.5 times the design load of 83T (design load intensity of 10 t/m²).
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**Fig.5** Load vs settlement on single & group column test

From the single column test results as shown in Fig.5, it was observed that the settlements under an ultimate test load of 53 T (15 t/m²) was less than 3 mm and for the design load of 35T (10 t/m²), it was less than 2 mm as against 12 mm based on IS 15284, Part-1 Cl.13.7 j., which indicates the much higher load carrying capacity of the stone columns than the design load.

From the group column test results as shown in Fig.5, it was observed that the vibro stone columns are adequately and satisfactorily carried out by bottom feed displacement method to carry out the stipulated design loads within the allowable settlement limits. Further the settlements under an ultimate test load of 125T (15 t/m²) was less than 5 mm for the design load of 83T (10 t/m²) it was less than 2 mm as against 30 mm based on IS 15284, Part-1 Cl.13.7 j. which indicates the much higher load carrying capacity of the stone columns than the design load. However safe bearing pressure is limited to 10 t/m² as per project technical specifications.

**Pile foundations with ground improvement**

The lateral pile capacity recommendations are provided based on the initial load tests and theoretical calculations. To arrive the required lateral capacity of 600 mm BCIS pile, the no. of stone columns required around the pile is found by the trial tests. Lateral load test conducted on Initial Test Pile (ITP), ITP-1 and ITP-2 as per the configuration shown in Fig.6, up to 3 times the design load (7T) in the coal stock pile area and the load test results are in order to achieve the required lateral capacity as given below.

**Fig.6** Configuration of stone columns for lateral load tests of ITP-1 & ITP-2

From the test results as indicated in Fig.7, it can be inferred that the ground improvement scheme with the above mentioned stone column configuration is successful in providing required lateral capacity (7T) to the piles with net deflection of less than 1.5 mm. However the stone column arrangement around piles to achieve required lateral capacity and to mitigate the liquefaction problem, has been changed in consultation with consultant (NTPC).

**Fig.7** Load vs deflection for ITP-1 & ITP-2

The pile lengths are calculated by considering the ash density of 1.3 t/m³ and soil density of 1.8 t/m³. Theoretically, the arrived length of piles is greater than the load test piles for same capacity. However as per technical specification, the final capacity of pile shall be considered as the least of the theoretical and field test results. To minimize the initial load tests, it has been decided to make the CHP area in to two zones (Zone-I & Zone-II) based on the available depth of ash below FGL. The pile load test results are presented in the following sections.

**Sequence of Ground Improvement**

To identify the improvement efficiency of the flyash based on the sequence of ground improvement, it has been envisaged to conduct the initial pile load test in two different ways in two zones. For Zone-I, Installation of BCIS piles followed by the stone columns and for Zone-II, Installation of stone columns followed by the BCIS piles with one additional lateral load test.

**Zone-I**

Depth of fly ash in the area covering Zone-I is approximately 10.50 m below FGL. Hence it becomes essential to increase the lateral capacity of piles installed in fly ash which is highly susceptible to liquefaction and offers poor lateral resistance to piles. For this purpose, vibro stone columns were installed around the piles by means of dry method to resist the pile from excessive lateral deflection. Stone columns of 500 mm dia. spaced at 1.5 m c/c laid in equilateral triangular pattern were installed around the piles. The test piles details are given in Table 1.

From the test results as shown in Fig.8, it can be inferred that the deflection achieved for the design load of 7 T is very nominal (<1 mm) and deflection for the ultimate load of 21 T is less than 6 mm. which indicates the much higher load carrying capacity of the pile.
Depth of fly ash in the area covering Zone-II is approximately 10.50 m below FGL. Stone columns of 500 mm dia. spaced at 1.5 m c/c laid in equilateral triangular pattern were installed before the installation of BCIS piles. The test pile details are given in Table 2.

Table 2 Load Test Details in Zone-II

<table>
<thead>
<tr>
<th>Sl. No</th>
<th>Load Test Details</th>
<th>ITP-07</th>
<th>ITP-08</th>
<th>ITP-09</th>
<th>ITP-10</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Type of Load on Pile</td>
<td>Lateral</td>
<td>Compression</td>
<td>Tension</td>
<td>Lateral</td>
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<tr>
<td>2</td>
<td>Dia. of Pile (mm)</td>
<td>600</td>
<td>600</td>
<td>600</td>
<td>600</td>
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<tr>
<td>3</td>
<td>Design Load (T)</td>
<td>7</td>
<td>140</td>
<td>28</td>
<td>7</td>
</tr>
<tr>
<td>4</td>
<td>Test Load (T)</td>
<td>21</td>
<td>420</td>
<td>84</td>
<td>21</td>
</tr>
<tr>
<td>5</td>
<td>Length of Pile below FGL (m)</td>
<td>32</td>
<td>32</td>
<td>32</td>
<td>32</td>
</tr>
</tbody>
</table>

Fig. 8 Load vs deflection for ITP-4

Zone-II

From the Zone-II test results as shown in Fig.9, it can be noted that, the settlements are reduced compared to Zone-I results with same test loads due to the sequence of ground improvement process; And based on the various field test results, the proposed ground improvement system with 500 mm dia. stone columns at 1.5 m c/c around 600 mm dia. RCC BCIS piles and 900 mm dia. stone columns at 2.0 m c/c in triangular pattern for shallow / open foundations are more than adequate to meet the design requirements.

SUMMARY

1. The dynamic cone resistance values have increased significantly in the improved ground with increase in depth. The increase in percentage is varying from 150 to more than 500 and also it was noticed that the increase of in-situ strength of ash increases with the increase of stone column diameter.
2. Based on the stone column test results for open foundations with 900 mm dia. stone columns at 2.0 m c/c in triangular pattern, the safe bearing capacity can be increased up to 15 t/m² in flyash fills with a density of 1.3 t/m³.
3. Based on the test results of ITP-1 & ITP-2, single row of stone columns beyond pile are sufficient to achieve the design lateral capacity (7 T) for 600 mm dia. BCIS piles for non-earthquake prone areas. However it is advisable to provide two rows of stone columns beyond the pile for earthquake prone areas.
4. Lateral deflections are reduced with increase in the diameter of stone columns around the piles.
5. Minimum reduction in settlements and lateral deflections are noticed for the Zone-II tests, due to improvement of ground before installation of the piles. However, it shall be advisable to adopt the proper sequence of improvement based on the construction feasibility.

REFERENCES