GROUND STRENGTHENING BY VIBRO-STONE COLUMNS—A CASE STUDY

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ABSTRACT: Vibroflotation based Stone Columns were installed at a Debottlenecking project at U.P, about 150km south-east of New Delhi. Initial geotechnical investigation data revealed sub-surface conditions chiefly comprising Silty Fine Sand–Silty Clay deposits with poor SPT Blow count for top 8 to 10 m depth. The top stratum had inadequate bearing capacity to take up the desired structural loads within serviceability limits, and hence the necessity of ground strengthening measures was felt. In addition, this measure was expected to mitigate the risk of liquefaction of the ground, since this region fell under zone III/IV of seismic map of India. Ground strengthening involved use of Vibroflotation technique to install 7 to 8 m deep Stone columns spaced at 1.8 to 2.5 m c/c at a triangular grid. Desired Net Safe Bearing Capacity after ground strengthening measures were 20 T/m² and 15 T/m² depending on the structures and their location. This paper presents basic equipments used, installation process, terminating criteria and the quality control measures adopted. Validation of improvement of the ground strength was undertaken by monitoring the pre- and post-treatment SPT/ DCPT values. The importance of Vibro Stone column technique as a ground strengthening measure, in alluvial tracts of Northern India is demonstrated through the proposed paper.

1. INTRODUCTION

Vibrofloation as a strengthening technique of weak natural soils and fills are now well established and documented. Numerous examples have been published on vibrofloation applications to typically loose sandy/ silty to soft and alluvial silty-clayey soils (Ketkar & Telang, 1994; Manish Kumar, et al., 2002). The type of structures supported vary from petroleum tankages, industrial plants, single and multi-storeyed buildings and towers. The method is primarily used for improving bearing capacity, limiting settlements resulting from vertical structural loads, and also for related applications such as embankment stabilization. Installation of stone columns particularly facilitates drainage action and permits rapid dissipation of pore pressures, and prevents shear failure of soils with low cohesion.

Way back in 1936, development of vibroflot was pursued separately in Germany and the USA, which lead to two machines of similar capabilities but of differing mechanical details. Until recently these two basic designs, with minor modifications have been most widely used in the western world, although little known post-war variants were produced in Russia and Japan (Greenwood, 1970).

This paper encompasses the developments and growing field applications in the vibroflot technology in India; and presents a case study of its application at a Debottlenecking project near New Delhi.

2. VIBROFLOTATION TECHNIQUE

Vibrofloation technique employs a mechanical vibration and uses water/air jet to shake and float the soil particles into a denser state. The equipment consists of a vibroflot suspended to a crane or Kelly operated hydraulic rig. The vibroflot itself consists of long tube approximately 400 mm in diameter, lower part of which contains a vibratory unit and hydraulic motor. Vibration is set up by a 90 kg eccentric shaft which rotates at 1800 rpm developing a centrifugal force of approximately 10 MT. A diagrammatic section through a vibroflot is shown in Figure 1.

Vibro-Stone columns are essentially a vibro-replacement application of vibrofloation technique. In vibro-replacement technique, crushed stones are inserted and vibrated into the ground. Originally, the Wet Top Feed method called for pouring stones from the top of the hole created by vibroflot and use of water to displace soil and allow the stones to get

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to the bottom in the interstice between the vibroflot and the wall of the hole. The vibro needle sinks under its own weight into the saturated soil. When the machine has reached the base of the stratum to be compacted, water supply is cut-off from the lower jet and transferred to the lateral jet source near the top of the vibroflot. Selected stones, usually of 75 mm downsized range, are filled from the crater formed at the top, and as the surrounding soil is compacted, the vibrating unit is slowly raised to the surface.

Fig. 1: Essential Features of Vibroflot

If, slurry and muck disposal is inconvenient and environmentally prohibitive, then Dry Bottom Feed method is applied, which has the stones fed directly to the tip of the vibroflot and achieving penetration by jetting high pressure air into the ground. Dry technique is known to create stone columns with diameter range from 600 to 1000 mm. In either approach, the quantity of stones required depends on the initial relative density of the stratum and the spacing of the compaction points. In very loose sands, each point may consume 0.6 cum for each meter of penetration.

3. FAVOURABLE SOIL CONDITIONS

Vibro-Stone columns are suitable for soils with fines content exceeding 10–15% range. Examples of soil categories are Silty sands, Sandy silts, Silts and Clays – that is, soils of adequately cohesive nature. As a general guide, formation of stone columns is facilitated in soils of permeability less than 10 to 1 micro.m/ sec. The coarse stones added reduce attenuation of the vibrations and facilitates drainage.

Genuine soil cohesion inhibits vibratory compaction and together with low permeability, causes clayey soils to be virtually unaffected between treatment points. Such soils are strengthened by filling the bore with granular stones leading to formation of stone columns. Subject to the technique of construction, granular stone columns can almost always be formed in soft clays of strength greater than 7.5 kPa. The bearing capacity of this treated ground is dependent upon the degree of support provided by the natural clay to the columns, as well as on the column diameter; constituents and state of compaction. In soft cohesive soils, therefore, the controlling factor on the use of the process is usually the tolerance of the structure to settlements.

4. IMPORTANT VIBROFLOTATION APPLICATIONS IN INDIA

Vibroflot technique was first introduced in India by the authors’ firm for a compressor foundation of M/s E.I.D. Parry Limited at Ennore, Madras in 1961. Background information on some of the important vibroflotation based stone column installation in India by authors’ firm is stated.

4.1 Plant Foundation

1200 stone columns to depth between 6 to 8 m were installed at Rampur (U.P) for a proposed Xerox plant. They were designed to support footings with allowable bearing pressure of 300 kPa and settlement of 20 mm.

4.2 Petroleum Storage Tanks

Some of the projects involving petroleum product storage tanks supported on stone columns are: Haldia, W.B. (for three 79 m dia oil storage tanks, about 7000 stone columns spaced at 2.0 m c/c and installed to a depth of about 14 m below ground level); Paradeep, Orissa (14287 stone columns 10 m deep @ 2.0 m c/c in triangular grid for 7 nos petroleum product tank and 2 nos fire water storage tanks); Mundra, Gujarat (9967 Stone columns for 4 nos, 89 m dia, 12 m high petroleum product tanks, spacing at 1.8 m c/c in triangular grid); Mahul, at Mumbai (1410 stone columns for 2 nos., 34 m diameter, @ 1.3 m c/c triangular grid); Kalol & Mehsana (3600 stone columns for 12 nos., 32 m diameter, @ 1.5 m c/c triangular grid).

4.3 Gas Turbine Plant

1420 stone columns installed for Administrative building, Switchyard, Transformer and Storage tanks at New Delhi to improve the bearing capacity to 200 kPa.

These and other Stone column installation at Uran, Mumbai; Elathur, Kerala; Mangalore; Madras etc are instances of increasing application of Vibro-Stone columns to support vital installations in India.

5. CASE STUDY

The site under consideration is located about 150 km south-east of New Delhi in the Indo-Gangetic plain of India. Ground improvement had been carried out in the past at the
near vicinity of the same site to densify the ground and as a counter measure against liquefaction, since this site falls under seismic zone III/IV. Structures like 106 m tall Prilling tower, compressors, storage tanks for ammonia and naphtha, pipe rack, process columns upto 70 m height, a two span workshop and bagging plant were successfully supported in the past on vibro-stone column improved ground.

Keeping in view the successful use in past, vibro-stone column scheme was proposed to strengthen the ground of this factory premise. The units and sections of plant under purview of ground strengthening were: Ammonia Fire Heater (AFH-Cluster 1); Ammonia Cooling Tower (ACT-Cluster 2); Urea Cooling Tower (UCT-Cluster 3); Urea Solution Tanks (UST-Cluster 4); Bulk flow conveyor and other related ancillary units (Fig. 2).

Idealized sub-surface condition at the proposed area is reported in Figure 3. The borelog indicates top 2.5 m stratum consisting of Clayey Silt (ML–CL) with SPT blow count typically in the range of 5 to 6. Underlying stratum chiefly comprised Fine Sand (SM) having increasing relative density values with increasing depth. Blow count was seen to increase from 6–13 at a depth range of 4 to 10 m to about 33–84 at 20 m depth. At certain locations, interventing layer of Stiff Silty Clay (CL) with calcareous nodules were reported. This layer was reported beyond 12 m, with SPT N varying from 16 to 30. Ground Water Table was reported at 2.8 m below ground.

2300 Vibro-stone columns 7.5 m deep were proposed, spaced at 1.8 m and 2.5 m c/c in triangular grid depending on the structures. Average diameter of the stone column was expected to be in the range of 800 to 850 mm. Overall work on ground strengthening was to be carried out to ensure that the sandy stratum attained a relative density of 75 to 85%. Backfill materials for stone column installation were 75 mm down stone aggregates conforming to gradation indicated in Figure 4. These materials were hard basaltic, durable material brought from Haldavani village at a lead of 180 kms.

5.1 Installation and Monitoring

Installation of stone columns was carried out in a grid as per approved plan. Vibroflot probe of about 400 mm diameter was suspended from a crane vertically over a pre-decided stone column point. Valve in the hydraulic pack was opened to induce vibration to the vibroflot (frequency kept between 1600 to 1800 rpm). Simultaneously, water valve was released to emanate water jet through nose cones at the bottom of the
vibro probe at a pressure between 3.5 kg/cm² to 5 kg/cm². The Vibroflot penetrated into the ground under its own weight and through the combined action of vibration and water jet.

Following criteria for Stone column termination was adopted, whichever was observed earlier:

i) Achieving required depth of 7.5 m from existing ground level.

ii) Decrease in rate of penetration of vibro-float to 0.5 m per minute.

iii) Tilting of vibro-float / rattling sound.

On reaching the required depth, bottom water jet was shut off while the flow of water from top of vibroflot was switched on. Nominal 75 mm down stone aggregates were poured from the top through the annular space. The vibroflot was withdrawn in stages maintaining maximum lift to 0.8 m and stone back filling was continued up to ground level. For effective vibro compaction of the stone aggregate increase in hydraulic pressure was maintained in the range 17 to 20 kg/cms² and the vibroflot extraction rate was maintained compatible with the rate of stone backfilling.

The boring time, compaction time, length of boring were recorded for each stone column. The consumption of stone backfill material was also recorded area wise/structure wise.

6. PERFORMANCE OF GROUND IMPROVEMENT MEASURES

Prior to ground improvement measures, Standard Penetration Tests (SPT) were conducted in the vicinity of treated areas, which were part of the initial geotechnical investigations. For establishing the effectiveness of stone column installation, post treatment SPT/Dynamic Cone Penetration Tests (DCPT) were undertaken using continuous bentonite mud circulation at selected points as per IS: 2131 and IS: 4968 (Part II) respectively. These tests were conducted at the centroid of the intervening area between the stone columns.

Cluster areas for improvement stated earlier and reported in Figure 2 were used for validating the effectiveness of ground strengthening measures. As a part of studies, Pre- and Post-SPT/DCPT were compared thoroughly; any ambiguous data were discarded and not considered for comparison.

Comparative results of pre- and post-SPT at Cluster areas 1, 2 and 3 are reported in Figure 5. It is seen that, the only contradictory observation that exists is similar post-SPT value at GL in AFH-Cluster 1 and is possibly due to soil disturbance. Again, in the same figure, a very high post-SPT is indicated at 3m, which may be ambiguous, but nevertheless represent ground strengthening. Barring these observations, significant soil densification is indicated in Figure 5.

Validation exercise at various clusters is also undertaken by converting pre-SPT blow counts to equivalent DCPT blow count. Preliminary comparative exercises indicated an approximate correlation factor of 1.5 between measured SPT and DCPT Blow count (that is, \( N_{dcpt} \approx 1.5 N_{spt} \)). Pre-treatment SPT N values were converted to DCPT N, and the resulting comparative curves are reported separately for each cluster in Figure 6.

Improvement in stratum strength is seen in top 6 m, which is considered as a depth under the direct influence of stone columns. Beyond about 6m, the pre-and post- DCPT curves are nearly seen to overlap (Fig. 6, Clusters 3 & 4). Noteworthy trend in the improvement is seen in form of sudden increase in the post-DCPT values at about 3m depth, which is the transition from clayey silt layer (ML-CL) and Loose to Medium Fine Sand (SM).

![Fig. 5: Comparative Performance of Ground Strengthening Using Pre-Post SPT Data](image-url)
7. CONCLUDING REMARKS

In the foregoing sections, limited comparative data of the case study illustrate the effectiveness of vibro-stone columns in strengthening silty sandy alluvial typical of Indo-gangetic plains.

Higher relative stiffness of stone columns leads to a very significant reduction of the overall compressibility of the treated soil. Vibro-stone columns have on several occasions replaced piles to support many critical structures like oil tankages, pipe racks and industrial sheds leading to a very high degree of economy and speedy construction.

ACKNOWLEDGEMENT

The authors acknowledge with gratitude the encouragement and support from ITD Cementation India limited. Sincere appreciation to the Owner and Consultants of the project for their constant interactions and discussions leading to refined execution of project.

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