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Ground Improvement Technique – A View of Stone Column Method with the Case Study

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ABSTRACT: The ground improvement technique is a special method aimed at increasing bearing capacity, reduce compressibility, decrease permeability, modify dynamic response, and reduce the risk of liquefaction potential of subsoil and increase the stability of soil in slopes. Stone columns are a ground improvement technique to improve the load bearing capacity and reduce the settlement of the soil. On many occasions, it is noted that the local soil is by nature, unable to bear the proposed structure. Hence the use of ground improvement techniques may be necessitated. Use of stone columns is one such technique.

I. INTRODUCTION

Though the term Ground Improvement has been familiar to Civil Engineers, the design approach is still empirical, mostly based on past experience. Well defined design procedure, constructions procedure and codal provisions are yet to be developed. In the absence of above, execution of the same is difficult and sometimes lead to contract disputes.

On the other hand, adequacy of Ground Improvement for supporting even large structures has been proved beyond doubts. Application of Ground Improvement is not only cheaper but reduces the construction time significantly. In last two decades several major projects have been successfully built in the country adopting some of the ground improvement techniques. For each project, field trials and ground monitoring has been carried out. This has generated large amount of field data and built the confidence of geotechnical designer for adopting ground improvement techniques.

II. OCCURRENCE OF WEAK DEPOSITS

Weak deposits can be defined as deposit, which has one or more of the following:

i. Low shear strength
ii. High compressibility
iii. Susceptibility to liquefaction

Such deposits are very common along the coastal region. Most of the marine deposits are of recent origin and have not undergone much consolidation. As a result, they have low shear strength or high compressibility. Typical places with such soft clay deposits are Kandala, Nhava Sheva, Cochin, Ennore, Kakinada, Visakhapatnam, Haldia, Calcutta, etc. Even some of the land deposits, particularly alluvial deposits along the river belt have loose silt/sand to a large depth. Typical example is large area of gangetic belt in Uttar Pradesh. Even man made deposits such as mine back-fill or land reclaimed by filling can have inadequate strength properties requiring ground improvement.

Major problems associated with such deposits are:

i. Low bearing capacity
ii. Higher settlement (both total and differential)
iii. High seepage losses
iv. Liquefaction during earthquake
v. Instability of foundation excavations
vi. Higher earth pressures on retaining structures

In early days, areas having such deposit were avoided for construction. But with scarcity of land in urban areas, we do not have choice and structures have to be built on weak deposits. Pile foundation is of course a possible approach as it by pass the weak deposit and transfer the load on next competent layer. Where thickness of deposit is very large, pile foundation is uneconomical and time consuming.

Number of industrial plants in last one or two decades have successfully adopted one of the ground improvement techniques. This has resulted in either elimination of RCC piles or considerable reduction in number of RCC piles. Wherever ground improvement technique has been adopted, it is observed that there is reduction in construction cost and also the construction is faster.

Most of the plants in India are constructed based on Lumpsum Turn Key Project (LSTK). The work is awarded to the bidder who provides the lowest prices but at the same time meeting all technical requirements. The construction agencies always look forward to improve the ground wherever possible to minimize the total cost.

Numbers of techniques have been developed to improve the weak deposits such that required structure can be placed without pile foundation. Following section describes typical properties of weak deposits, methods available for ground improvement and finally few case studies on improvement carried out with different techniques.

III. STONE COLUMN

Stone columns are cylindrical columns made below ground level which comprises of granular material of large size varying from 25 to 100 mm. A hole is made in the soft deposit by different techniques and then filled with stones in layers and compacted to form the complete column. When a structure is placed over the area treated by stone columns, majority of the load (80-90%) is transmitted to the stone column because of their higher stiffness. Balance 10-20% of the load is taken by clay deposit. With the help of this 10% of surcharge load, the soft clay is able to provide adequate confinement to the cylindrical column. The maximum permissible actual stress on the columns can be predicted from the known theory.

The area treated by stone columns can be used to support only flexible structures such as embankment, oil storage tank, etc. because, the settlement even after treatment with stone column can be large (50-200 mm). Without stone columns the settlement could have been 3-4 times higher and also the bearing capacity would have been much less.

A. Area application of Stone column

In Construction and Civil Engineering projects, stone column can be used:

- To improve the stability of embankments and natural slopes.
- To increase the bearing capacity of a site to make it possible to use shallow foundation on the soil
- For the reduction of total and differential settlements.
- For the reduction of liquefaction potential of cohesionless soil.
- To increase the time rate of settlement

B. Benefits of Stone Columns

- Stone Columns are technical and potentially economical alternatives to deep foundation.
- Stone Columns are more economical than the removal and replacement of deep poor bearing soil on a large site.
- Very useful where infrastructure does not permit high vibration technique such as dynamic compaction, deep blasting or piling.
- Where time is critical to project start-up site improvement can be achieved quicker by vibroflotation than by pre-loading the soils.
- Stone Columns provide a vertical drainage path for excess pore water pressure dissipation.
- With Vibroflotation differential settlements are often in the order of 10% to 15% of total settlement.

IV. METHODS OF STONE COLUMN

Stone column technique has been developed very recently for improving bearing capacity and to reduce settlement of weak deposits like soft clays and loose sands. It has been increasingly adopted in India. This method involves making bore holes in the weak deposits and filling stone chips or gravel or mixture of these and compacting them to create a column of desired strength. These are constructed by adopting any one of the following methods.

i. Non-displacement Method

ii. Vibrofloated Stone Column.

A. Non-displacement Method

In this method a hole of required size is accomplished either by using bailer and casing or using rotary drill. Initially the borehole is advanced using a bailer while its sides are supported by a casing. After the casing has reached the required level, sound and well-graded crushed stone of 75mm down size of 2 mm is placed in the borehole and casing is withdrawn at a certain length to ensure continuous formation of stone column. The loose charge below the bottom of the casing is then compacted by operating a rammer of suitable weight and fall within the casing, so as to obtain compaction energy of ground of 20 kN m per blow. The sequence of formation of stone column is shown in Figure 1.

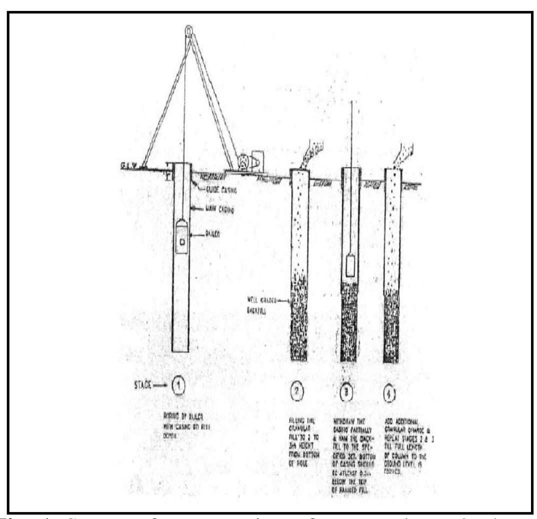

Fig. 1. Stages of construction of stone column by bored piling equipment (Non – Displacement Method)

B. Vibrofloated Stone Columns

In this method a hole is formed in the weak deposit using a vibrofloat unit.

The vibrofloat equipment comprises of a vibrofloat probe, accompanying power supply, water pump, crane and front - end loader as shown in Figure 2.The vibrofloat is a poker vibrator normally of diameter varying from 300 mm to 450 mm and about 2m to 3.5m long weighing 2 to 4 tones depending upon the size (Figure 3).

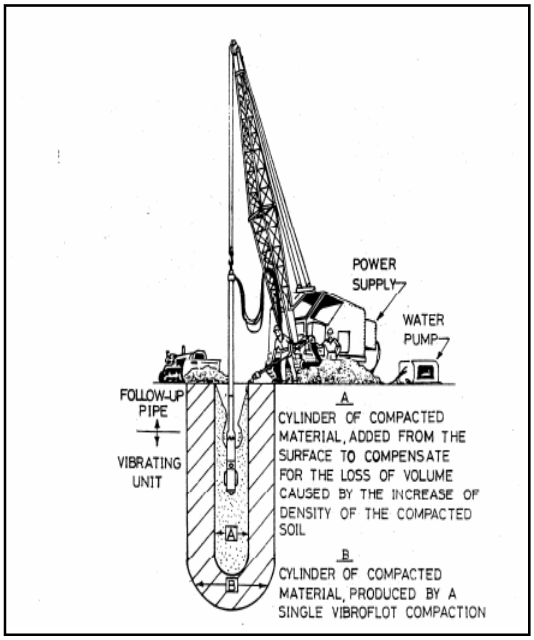

Fig.2. Vibroflotation equipment (After Brown,1976)

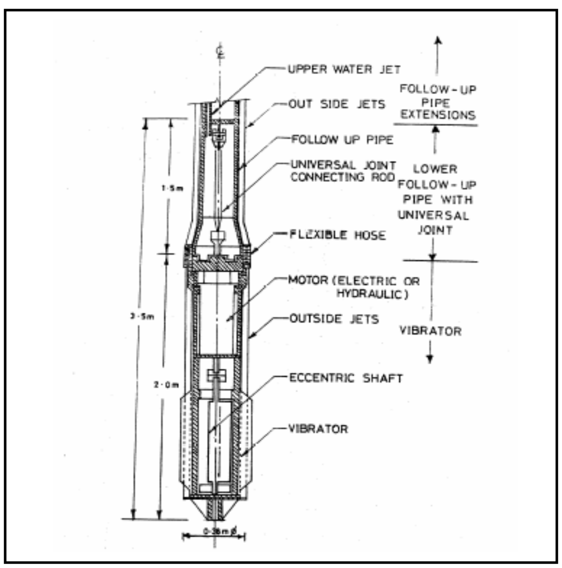

Fig. 3. 100HP Viroflot (After Brown,1976).

By this method soil generally gets replaced by jetting water used with the vibro float, size of the hole formed can be controlled to a certain extent, by regulating intensity of vibration, pressure and rate of penetration of float. Diameter of holes formed varies generally from 0.8m to 1.1m. After the vibrofloat has penetrated to the desired level it is gradually withdrawn and crushed stone is poured. During the process of withdrawal of the needle, vibration and jetting is continuously maintained to ensure compaction of granular fill. The withdrawal of the float is made in short passes, preferably of about lm to ensure proper compaction and uniformity along the entire length of stone column. The sequence of constructing the column by vibrofloat is as shown in Figure 4.

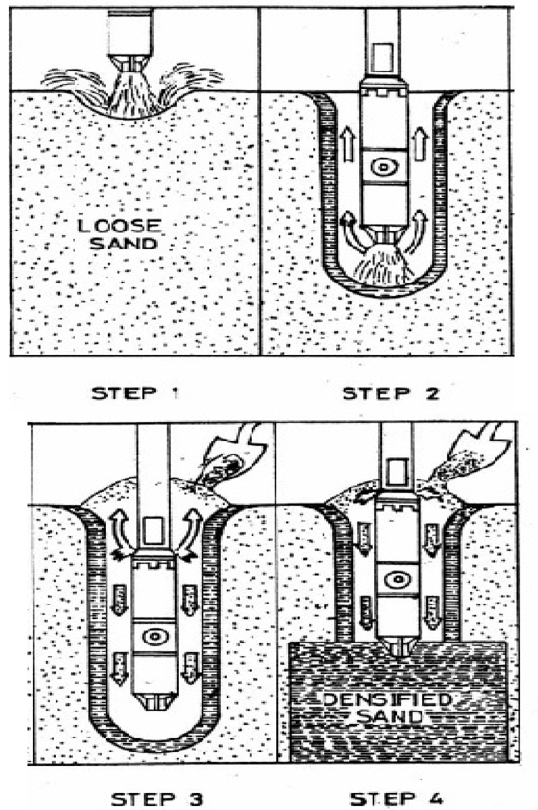

Fig. 4. Vibroflotation compaction Process (After Brown, 1975).

V. DESIGN OF STONE COLUMN

Design of stone column reinforced ground involves two aspects.

1. Estimation of load capacity of a stone column
2. Settlement Analysis.

A. Estimation of Load capacity of a stone column

Load capacity of the treated ground may be obtained by summing up the contribution of each of the following components for wide spread loads, such as tankages and embankments:

a) Capacity of the stone column resulting from the resistance offered by the surrounding soil against its lateral deformation (bulging) under axial load,

b) Capacity of the stone column resulting from - increase in resistance offered by the surrounding soil due to surcharge over it, and

c) Bearing support provided by the intervening soil between the columns.

Capacity Based on Bulging of Column. Considering that the foundation soil is at failure when stressed horizontally due to bulging of stone column, the limiting (yield) axial stress in the column is given by the sum of the following:

$\sigma_v = \sigma_{rL} \; K_{pcol}$ ....(1)

$\sigma_v = (\sigma_{ro} + 4C_u)K_{pcol}$

where σ_v = limiting axial stress in the column when it approaches shear failure due to bulging, and

σ_{rL} = limiting radial stress = $(\sigma_{ro} + 4C_u)$

where C_u = undisturbed undrained shear strength of clay surrounding the column, and

σ_{ro} = initial effective radial stress = $K_0\sigma_{vo}$

where K_0 = average coefficient of lateral earth pressure for clays equal to 0.6 or alternatively, as determined from the relationship Ko = 1 - sinφ,

where φ is the effective angle of internal friction of soil, and

σ_{vo} = average initial effective vertical stress considering an average bulge depth as 2 times diameter of the column, that is $\sigma_{vo} = \gamma 2D$

where γ = effective unit weight of soil within the influence zone.

$K_{pcol} = \tan^2 (45^o + \varphi_c/2)$

Where φ_c = angle of internal friction of the granular column material and it may vary depending upon angularity, surface characteristics and density of column material. As a broad guide, the φ_c may range from 38° to 42° de-pending upon the compactness achieved during. construction of stone columns.

Yield load = $\sigma_v \pi D^2/4$

Safe load on column alone

$Q_1 = \sigma_v (\pi/4 \, D^2) / 2$ ....(2)

where 2 is the factor of safety.

Surcharge Effect. The increase in capacity of the column due to surcharge may be computed in terms of increase in mean radial stress of the soil as follows:

$\Delta\sigma_{ro} = q_{safe}/3 \; (1+2K_0)$ ....(3)

Where $\Delta\sigma_{ro}$ is the increase in mean radial stress due to surcharge, and $q_{safe}$is the safe bearing pressure of soil with the factor of safety of 2.5 (See IS 6403)

$q_{safe} = C_uN_c / 2.5$

Increase in yield stress of the column = $K_{pcol}\Delta\sigma_{ro}$

Allowing a factor safety of 2, increase in safe load of column, Q2 is given by the following formula:

$Q_2 = (K_{pcol}\Delta\sigma_{ro}A_s)/2$ ....(4)

The surcharge effect is minimum at edges and it should be compensated by installing additional columns in the peripheral region of the facility.

Bearing Support Provided by the Intervening Soil. This component consists of the intrinsic capacity of the virgin soil to support a vertical load which may be computed as follows:

Effective area of stone column including the intervening soil for triangular pattern = $0.866 \, S^2$

Area of intervening soil for each column, A_g is given by the following formula: $A_g = 0.866S^2 - (\pi D^2/4)$

Safe load taken by the intervening soil,

$Q_3 = q_{safe} \, A_g$ ....(5)

Overall safe load on each column and its tributary soil = $Q_1 + Q_2 + Q_3$

B. Settlement Analysis

The settlement of stone column treated ground may be determined by either the empirical approach or the concept of vertical average stress on the soft soil. In the empirical method the settlement of treated ground is computed as a percentage of untreated ground settlement. For a given spacing of stone column and strength of the soft ground, the settlement of the reinforced ground can be obtained from the Figure 5.

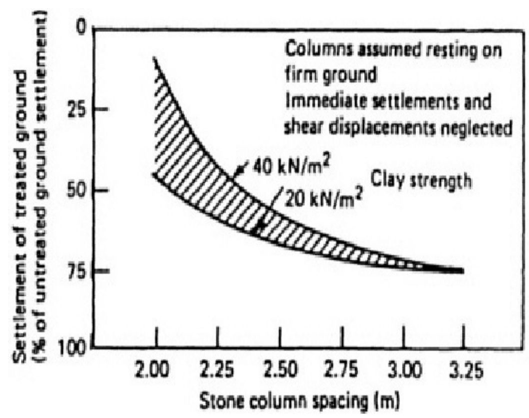

Fig. 5. Effect of stone column foundation on anticipated foundation settlement.

In this method it is assumed that the column rests on sufficiently hard ground. In the reduced stress method, the settlement of the treated ground depends upon two parameters namely stress concentration factor, n, and the area replacement ratio, as. Factor, 'n' depends on the relative stiffness of the stone column and generally varies from 2 to 6 with usual values of 3 to 4. The area ratio, a_s is determined from the diameter and spacing of stone columns provided. Consolidation settlement S_t of treated ground is determined by the equation given below:

$S_t = \beta S$

Where β = Settlement reduction factor

$= 1/(1+(n-1)a_s)$

$n = \sigma_s/\sigma_c$

σ_s = Vertical stress in compacted stone column

σ_c = Vertical stress in surrounding soil = $A_{sc}/(A_{sc}+A_s)$

A_{sc} = Area of stone column

A_s = Area of soil surrounding the stone column

VI. CASE STUDIES ON STONE COLUMN TECHINQUES

Large numbers of major projects in the country have adopted one of the methods described above. Few typical case studies are highlighted here. In each case, field measurements have been made to find the property of the deposit before and after treatment.

A. Jetty Facilities at ICTT, Vallarpadam, Kochi

Introduction: Dubai Ports (DP World) is developing an International Container Transhipment Terminal at Vallarpadam, Kochi, India (refer Figure 6). This all weather port is strategically located on the East-West trade route on the South West coast of India. It is expected that the proposed terminal will handle a Million TEU's of transhipment traffic during the first phase by virtue of its strategic position.

Sub Soil Profile. The subsoil consists of 2 to 3 m thick silty sand followed by 17 m thick soft clay (tip resistance of 0.3 MPa to 0.6 MPa) and this is followed by 3 m thick loose sand. Following this layer, 13 m thick silty clay layer is found (tip resistance of 0.6 to 1.2 MPa). This layer is followed by very stiff to hard clay layers or dense sand layers.

Proposed Structures: It is proposed to construct a 600m long quay wall and associated container yard in the first phase (refer figure 7). The deck is to be supported on piles with a slope of 1V:3H.

Ground Improvement Scheme: To stabilize the slope below the Jetty and to reduce the settlements in associated structures, Vibro Stone columns of 1100mm diameter are being installed to an average depth of 22.5 meters at triangular grid spacing of 2.1m. The installation of Stone Columns was monitored using automatic data recording systems to ensure adequate depth of treatment and compaction effort.

Fig. 6. Artistic Impression of ICTT, Vallarpadam.

B. LNG Terminal at Hazira

Shell India is constructing two LNG storage tanks at the Hazira LNG Terminal. The diameter of the tanks is 84 m with a filling level of approx 35 m (Figure 8).

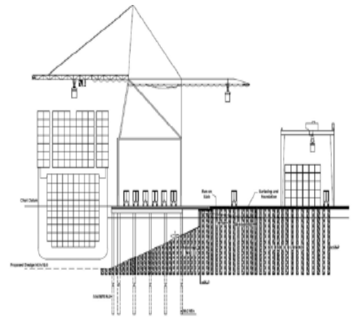

Fig. 7. Cross-Section showing Stone Columns along Quay & Associated Yard.

The sub soil at the site consists of loose to medium silty sand to a depth of 10m. Below this, alternating layers of sand and silty clay are present to a depth of 16 m. The top 3m were recently reclaimed material. The average fines content in the sand over the depth was in the range of 15% to 25%. Medium dense sand with SPT N> 30 was encountered below 16m.The poor subsoil conditions and the intensity of earthquakes in the region resulted in the requirement for soil improvement prior to construction of the tanks.

Treatment: The 34 m high LNG tank imposes a static design load of 230 kPa. In addition a maximum peak ground acceleration of 0.25 g is to be expected during a possible earthquake event. Ground treatment was therefore required to

a) Increase the density of the soil and thereby reduce the settlements of the tank under the static load to within 120 mm.

b) Reduce the liquefaction potential in the sand layer by strengthening the subsoil and also by providing effective drainage to prevent excess pore water pressure.

Vibro stone columns (Vibro Replacement) were selected to achieve the above objectives. The coarse permeable material of the column allows rapid dissipation of excess pore water pressure. The columns made up of highly compacted granular material act as a flexible reinforcement in the soil to increase the overall shear strength of the treated soil. During the process of column installation, sandy soil between the columns is densified.

Design: As per the design, 1.0 m diameter columns on a square grid spacing of 2.4 m c/c to a depth of 16 m from the existing ground level were to be installed. The annular width of treatment was extended beyond the tank edge by 10 m.

Column Installation. There are three distinct phases of installation. The first phase is penetration of the vibrator to the required depth for the first time. In the second phase, the hole is flushed by withdrawing the vibrator and repenetrating in to the hole. In the third phase, the vibrator is lifted up by about 1.0 m and then repenetrated by about 0.7 m in to the stone mass to form a highly compacted stone column.

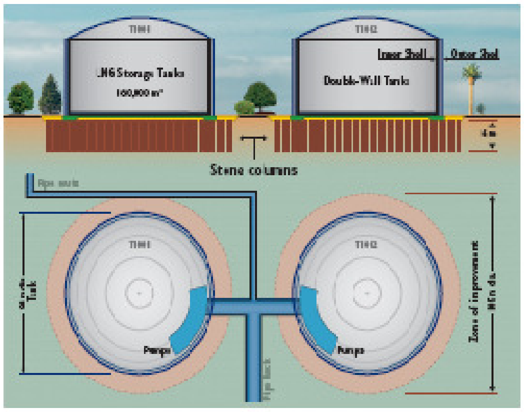

Fig. 8. LNG Tank founded on stone column.

VII. CONCLUSION

Numerous instances arise where the soil at many sites at shallow depths are not having required properties to support proposed structures.

In some situations, poor soil conditions may pose problem for the integrity of existing structures. In response to these needs special techniques for the in-place treatment of soils have been developed and are practical effectively. Among the several methods the techniques of stone column is one popular since the methods require less time to implement and improvement is quicker.

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