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A Review on Ground Improvement with Surcharge in Addressing Liquefaction Mitigation

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Abstract. Soil liquefaction and associated ground deformations have been a major source of damage to structures in the event of earthquake. Various ground improvement techniques are being practiced in mitigating liquefaction, across the world. However, handling silty soils having fines content more than 20 percent attracts special attention to the practicing engineers when compare to clean loose sandy strata. Improvement of silty soils using vibro stone columns is proven technology as this process ensures overall increase in shear strength and soil stiffness (i.e. reduction in settlements). Furthermore, application of surcharge over the treated area will be an added advantage as the increase in effective stress ensures enhancing the consolidation process. This paper covers a case study of ground improvement with surcharge in consideration of design mythology. In addition, prediction of time rate of settlement, performance assessment also discussed. Post treatment liquefaction analysis confirms the improvement in factor of safety against liquefaction.

Keywords: ground improvement, liquefaction, surcharge, silty soils, vibro stone column

1 Introduction

1.1 General

Development of oil & gas industry related infrastructure is major growing facilities in India. Storage structure like mounded storage vessels (MSV), spheres and tanks are very sensitive to found on liquefaction prone subsoils. Soil liquefaction have been a major source of damage to such structures during past earthquakes (e.g. 1964 Alaska earthquake, 1995 Kobe earthquake, 2001 Bhuj earthquake). In order to build foundations for such critical structures in similar environment, it is necessary to provide optimal foundation technique to meet their performance requirements. Various ground improvement methods namely deep vibro techniques, impact methods, blasting techniques, cement/admixture stabilization etc. are generally practiced improving clean cohesionless soils for mitigation of liquefaction [2,5,6]. However, densification of silty soil with fines content greater than 20 percent requires special attention [2].

Silty soils with high fine content and intermediate permeability, shows a complex behavior in seismic conditions [3,4]. Use of vibro stone columns with surcharge to mitigate the liquefaction in such silty soil studied in this paper.

1.2 Motivation and Objective

The structures like MSV and storage tanks can be effectively founded over ground improvement using vibro stone columns and have long proven track record [7,8]. Application of surcharge over treated ground to enhance time rate of consolidation controlling post treatment settlements. Optimal foundation accompanied by progressive design and time convenience by means of application of full or partial surcharge, can provide cost effective solution. Considering limited space in active bottling plant and execution feasibility, partial surcharging corresponding to 60% of design load was done. The objective of this paper is to highlight performance of ground improvement using vibro stone columns with surcharge in mitigating liquefaction potential of subsoil. Performance of ground improvement was monitored by application of large scale zone load test in this project.

2 Project and Site Conditions

2.1 Details of MSVs

Mounded storage facility consisting of 3 no's of bullets was proposed in active LPG plant in North India. Loading and performance requirements are given below:

- Loading intensity : 100 kPa
- Post construction settlement : $\leq$ 50mm
- Seismic Parameters : Zone-IV, PGA=0.24g and EM=7.5

2.2 Soil data and Geotechnical concerns

Confirmatory soil investigation via 2 boreholes were executed within the footprint of MSV. The maximum depth of exploration is about 25m below the existing ground level (EGL). The subsoil conditions reveal that alternate layers of clayey silt & sandy silt up to 4m followed by sandy silt up to the depth of 13m below EGL. This layer is followed by clayey sandy silt with presence of gravels up to the 18m below EGL.

Beyond 18m depth, the subsoil comprises of dense silty sand with presence of gravels followed by very dense silty sand up to the depth of exploration. Ground water table was encountered at 5m to 7m below EGL during the time of investigation. Pre SPT-N vs depth and gradation analysis is shown in Fig. 1. Mitigating liquefaction and limiting post construction settlement was required to be addressed considering the existing soil conditions.

The project location falls in earthquake zone IV and subsoil being loose sandy silt up to 12m to 13m depth, it was assessed soil get liquified. Liquefaction potential of sandy silts was evaluated using NCEER guidelines [11].

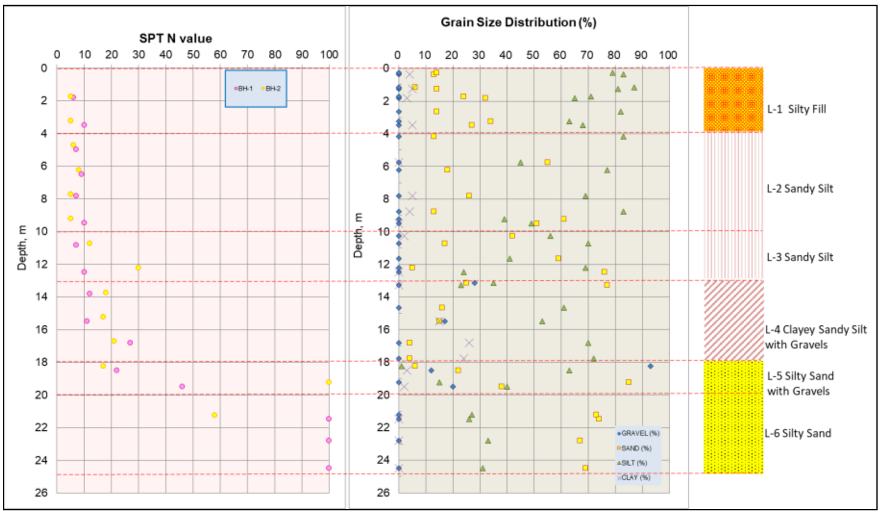


Fig. 1. Plot showing SPT-N, grain size distribution vs depth

3 Need for Ground Improvement

3.1 Background

As the subsoil at the proposed site being loose silt with clay to a depth of 13m, it will undergo excessive long-term settlements due to superimposed structural loads. Also, it will not have required bearing capacity to support the foundation of the MSV. In addition, the project location falls under seismic zone IV which might prone to be liquefaction, in event of earthquake.

Densification of silty soil may not immediately be obtained by ground improvement. The rate of settlement shall need to be accelerated by surcharging the treated ground. This process will not only help in densification of subsoil to reduce the liquefaction risk but also elude the excess post construction settlement.

3.2 Ground improvement technique

Ground improvement using vibro stone columns with surcharge was proposed to address the geotechnical concerns. introduces a coarse-grained material as load bearing elements and drainage element. Usually these coarse-grained materials consisting of gravel or stone aggregate as a backfill medium. Improvement of subsoil is mainly due to replacement of loose silty soil by strong aggregates and densification of soil in-between the columns. The densification occurs at slow rate over long period of time. Hence, densification of loose silty soils is further enhanced by applying surcharge over treated ground.

3.3 Improvement scheme

Ground improvement design is carried out according to Priebe's design methodology [9,10] using an in-house program "Keller Improvement Designer" (KID) by employing soil design parameters.

3.4 Surcharge over treated ground

The aim of the surcharge placement works is to preload the treated ground to attain effective stress that exceeds the pressure due to the design load. Determination of surcharge level is dependent upon the expected settlement and the future load. A more acceptable way of surcharging for such a project is to place a thickness equivalent to a multiplier of the predicted settlement to compensate for the shortfall resulting from the remaining degree of consolidation. Hence, partial surcharging corresponding to 60% of design load was placed which will not only address the issue of limited space and execution feasibility but also elude the excessive settlement.

Rate of surcharge filling maintained at site was in the range of 0.4 to 0.5 m/day. Construction monitoring and placement of surcharge over the treated ground was done on observational methodology during execution phase. Fig. 2 shows the typical schematics of construction stages for mounded storage vessel.

4 Post-Performance

About seven settlement plates were installed over treatment to monitor the settlement during loading and unloading of surcharge. Further post-performance investigation was done using bore holes and stone column load tests. Summary of post-performance analysis is discussed in next sections.

4.1 Settlements during surcharge

The settlement readings of each plate were recorded daily using total station**.** Fig. 3 shows the time vs settlement plot for known increment of surcharge loading. Following are key points:

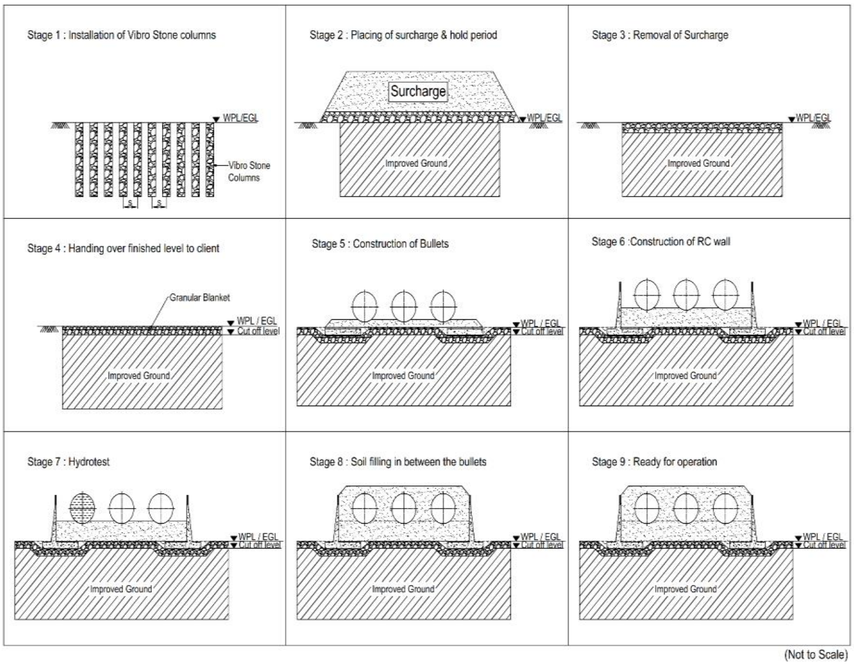


Fig. 2. Construction stages of mounded storage vessels

- Total settlement experienced by the plates was in the range of 25mm to 35mm after reaching full surcharge height.
- Rate of settlement was nearly stabilized after 3 days waiting period under full surcharge height and remained constant for almost 7 days. Total waiting period under full surcharge height was about 10 days.

Load increment was held until average 90% of the ultimate consolidation was achieved, using Asaoka's method [1]. In this method final settlement was determined by plotting settlement at time (t-1) as the ordinate and settlement at time (t) as the abscissa. The ordinate of the point of intersection of the aforesaid plot and a 1:1 line gives the ultimate settlement from which the degree of consolidation at the present stage can be determined. The expected ultimate settlement under surcharge load using Asaoka's method is summaries in Fig. 4. Average degree of consolidation based on this observational method is around more than 90%.

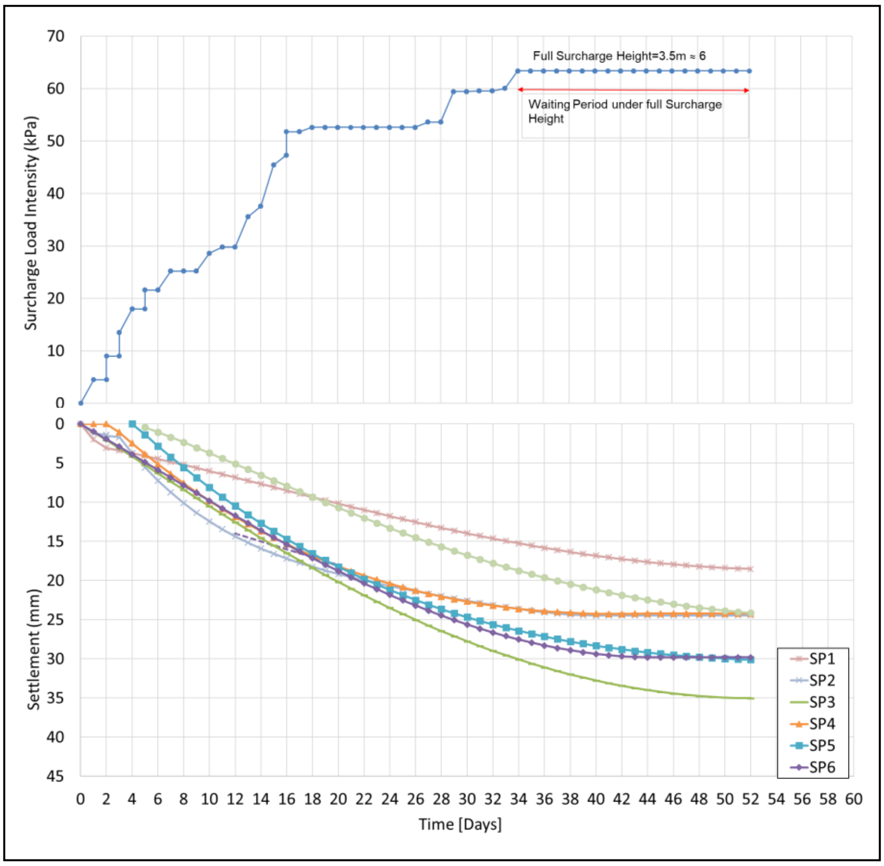
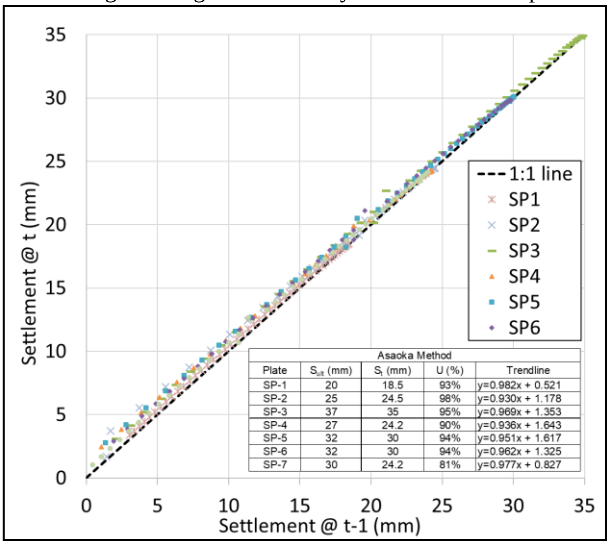


Fig. 3. Plot showing surcharge load intensity and settlement of plates w.r.t. time



Asaoka Method				
Plate	S_{ult} (mm)	S_t (mm)	U (%)	Trendline
SP-1	20	18.5	93%	y=0.982x + 0.521
SP-2	25	24.5	98%	y=0.930x + 1.178
SP-3	37	35	95%	y=0.969x + 1.353
SP-4	27	24.2	90%	y=0.936x + 1.643
SP-5	32	30	94%	y=0.951x + 1.617
SP-6	32	30	94%	y=0.962x + 1.325
SP-7	30	24.2	81%	y=0.977x + 0.827

Fig. 4. Plot showing estimation of ultimate settlement using Asaoka's method

4.2 Post treatment soil investigation

Post ground improvement soil investigation using boreholes was conducted after removal of surcharge. Considerable improvement is observed in the subsoil stiffness due to densification of the silty soil in between the columns. **Fig. 5** shows the SPT-N vs depth plot for pre & post improvement. It can be noticed that there is improvement in the stiffness of the subsoil.

Liquefaction analysis was carried out using post SPT-N values using NCEER guidelines [11]. The results indicate the considerable improvement in Factor of Safety (FOS) against liquefaction (see **Fig. 5**). Hence, it can be concluded that proposed treatment scheme has considerably reduced the risk of liquefaction in the event of earthquake.

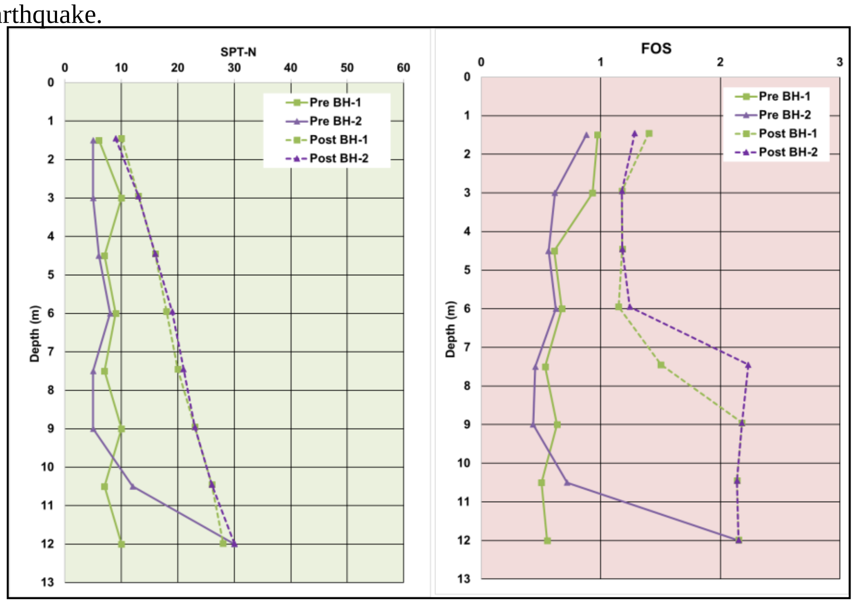


Fig. 5. Pre and post SPT-N values vs depth and FOS against liquefaction

4.3 Observations

Based on the post-performance results, it is observed that total settlement experienced due to surcharge over treated ground falls within the range of 25mm to 35mm during loading of surcharge. In addition, there is an improvement in the stiffness of the subsoil by approximately 2-fold in comparison to the estimated value.

5 Conclusions

Vibro stone columns have been effectively used to accomplish the required ground improvement in mitigating liquefaction and improving bearing capacity requirements. Pre and post soil investigation including large area zone load test is conducted to verify reflection of ground improvement. In addition to improving shear strength and compressibility parameters of soft soils, vibro stone columns ensures effective drainage paths to guarantee rapid consolidation prompting gain in shear strength of in-situ soils. Thus, the treatment with surcharge offered intense acceleration in the overall construction schedule and enabled the project completed within the stipulated time. Careful design, installation of stone columns with real time monitoring for quality control and post construction monitoring ensured stable foundation for the proposed structure resting on improved ground using vibro stone columns.

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