Vibro Compaction Technique in Liquefaction Mitigation And Its Value Addition - A Case Study

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Abstract. India being a rapidly developing nation requires quality infrastructural developments almost in every field ranging from industries, transportation, education, etc. Hence the stability of these structures should be least ensured against the geotechnical concerns like bearing capacity, settlement and liquefaction. The present study is about the development of an institutional campus located in seismically active zone. The proposed development comprises of both academic and residential buildings whose loading intensities ranges from single to maximum of 8 storeys proposed to rest on open/pile foundations. The subsoil comprises of loose to medium dense sand (fines<12%) revealed that the soil is susceptible to liquefaction. The deep vibro compaction (VC) technique considered to be an effective solution to mitigate the liquefaction and found to be an alternate foundation solution over the conventional piling method. In addition, fully automated real time quality control measures adopted to ensure the execution of VC works is also discussed..

Keywords: Liquefaction, deep vibro compaction, quality control measures.

1 Introduction

India being a fast-developing country with rapid urbanization, the scarcity of challenge free construction land increases which in turn forces the utilization of available land with suitable ground treatment. The major geotechnical challenges of these available lands are insufficient bearing capacity and excessive settlements. Apart from the above two, liquefaction possess a major threat in seismically active zones which got significantly distributed across the nation (seismicity map - IS 1893 part 1 :2016). This leads to the development of various techniques to mitigate the potential threat caused by liquefaction.

A phenomenon where the insitu soil loses its strength and stiffness due to the rapid change in the stress conditions mainly because of earthquake loading, causing the soil to behave like a liquid is known as liquefaction. It occurs predominantly in loose, uniformly graded, cohesion less fine to medium grained soils under partial or fully saturated condition.

The liquefaction potential shall be reduced significantly by densification (Vibro compaction) of the loose ground or by providing the required drainage path (Vibro stone columns) for dissipating the rapid buildup of pore water pressure. The densification process would certainly increase the cyclic resisting force, provided the presence of fines content is in the range of 10%-15%. Alternatively, the provision of drainage path would reduce the driving force.

A simplified procedure to evaluate the liquefaction potential was developed by seed and Idriss (1971), helps the practicing engineers to identify whether the insitu soil possess required amount of resistance (CRR-Cyclic Resistance Ratio) to counter the dynamic forces (CSR-Cyclic Stress Ratio). In general, the minimum FOS (=CRR/CSR) required against liquefaction potential shall be greater than 1. This paper deals with the case study where the vibro compaction method had been adopted for mitigating liquefaction and also addresses its value addition to the proposed project.

2 Deep Vibratory Techniques

2.1 Mechanism

The deep vibratory techniques include vibro compaction and vibro replacement methods. Based on the relationship between particle size and available vibro techniques the vibro compaction method was selected for this subject work. In this technique, the vibrator is lowered into the ground with the combination of vibration and high-pressure water jetting. The horizontal vibrations provided by the depth vibrators rearranges the sand particles to a dense configuration from its initial loose state. The desired compaction is achieved only if the induced vibratory force is enough to overcome the residual frictional strength available with in the soil. Based on the soil response to vibration, four different radial zones are defined surrounding the compaction point where the vibratory forces get attenuated with increasing radial distance from probe. The zones are fluidized zone, plastic zone, compaction zone and elastic zone as shown in Fig. 1. In saturated soil, the fluidized zone is developed when the pore water pressure buildup due to induced acceleration is greater than the rate of dissipation. This in turn reduces the effective stress and breaks the soil friction to allow the soil to rearrange into denser configuration. Hence the influence of compaction is mainly dependent on the radius of the fluidized zone. In case of dry soil, the water jetting plays a crucial role in the formation of fluidized zone. In plastic zone the soil will not be fluidized but the compaction energy shall be transmitted to shear the soil particles and forms closer packing. Further the compaction energy gets dampened and zone of zero improvement is reached. The reduction in void ratio due to the rearrangement soil particles causes subsidence which need to be backfilled at ground level to maintain the required reduced level of the site. The degree of compaction achieved at a point depends mainly on the characteristics of the soil being treated (Initial density, grain size, shape etc.,) and the vibrator (frequency, amplitude & acceleration of vibrations and holding time at each step.

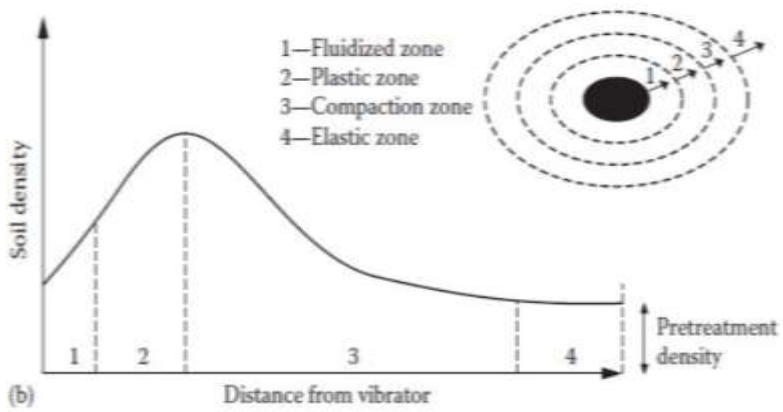

Fig. 1. Response of granular soils to vibration [Rodger 1979]

2.2 Installation Procedure

The vibrator is lowered into the ground under its own weight assisted by water flushing till the required depth and maintained at the same depth till the predetermined amperage or the pre-set time interval (30 s to 90 s) has elapsed, whichever is earlier. After satisfying the amperage/time criterion, the vibrator is raised to a pre-determined height (say 0.3m to 1.0 m) and again is held in position to satisfy the amperage/time criterion. These steps shall be repeated till the vibrator reaches the surface. The lift height, holding time and compaction amperage shall be finalized based on trial works.

3 Case study

3.1 Project background

The proposed development was for an institutional campus in North India which comprises of 15 structures including both the academic as well as the residential buildings which were planned to rest upon open/pile foundation systems. The proposed structures consist of single to maximum of nine floors with loading intensity ranges up to 150 kPa. The subsoil consists thick deposit of loose to medium dense sand with fines content less than 12%. The site being in seismically active zone (Zone IV; PGA-0.24 G), under earthquake conditions the soil deposits till 10m – 12 m depth was susceptible to liquefy. The upcoming sections deals with the soil characterization, performance criteria and implementation of the ground improvement works to mitigate liquefaction.

3.2 Subsoil Condition & liquefaction assessment

The soil investigation works carried out using the standard penetration results revealed the presence of loose to medium dense sand with fines < 12% till 10-12m followed by the dense sand layer till 15m. This layer was underlain by hard clay till the exploration depth as shown in Table 1. The ground water table during the time of investigation was approximately at 9m which was expected to be at shallow depth during the monsoon period. Later the confirmatory investigations were carried out using the Electronic Cone Penetration Test (ECPT).

Table 1. Subsoil profile

S No	RL (m)		Layer Thickness (m)	Soil Description	Tip Resistance (q_c, MPa)
1	59	57	2.0	Loose sand/ Firm clay	1-5
2	57	55	2.0	Medium dense sand	5-10
3	55	47	8.0	Medium dense to dense sand	9-15
4	47	44	3.0	Dense sand	13-16
5	44	39	5.0	Had Clay	> 4

Liquefaction analysis was carried out using the simplified procedure for evaluation of liquefaction potential given in IS 1893 (Part 1):2016. The maximum liquefiable depth varies from 5m to 12m across all structures. This could be very well understood from Fig. 2 where the plot between the depth and factor of safety against liquefaction was shown along with ECPT data.

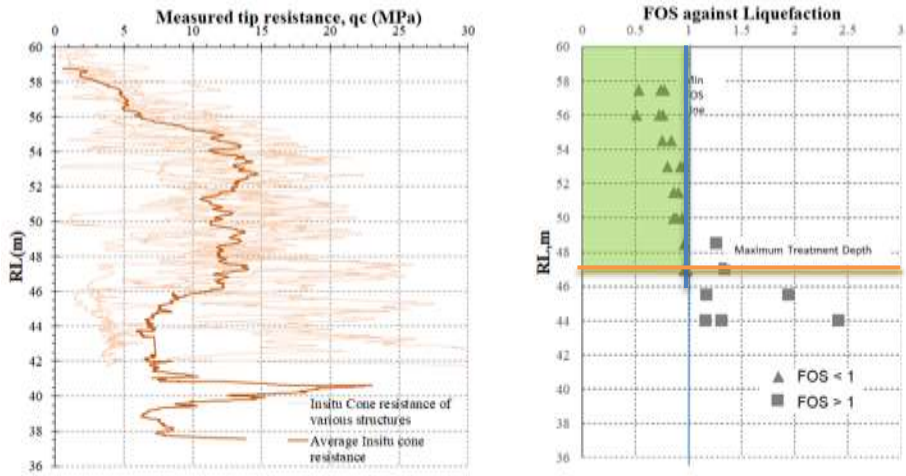

Fig. 2. Evaluation of liquefaction potential

3.3 Implementation of mitigation measures

Trial works

Before the execution of main works, the influential parameters like suitable spacing, compaction amperage, vibrator holding time of each lift required to achieve the minimum FOS of 1 against liquefaction were identified using trial works. The compaction points were spaced at 2.75 m and 3.0 m in triangular grid and the post ECPTs were executed at the weakest point of compaction as shown in Fig. 3. The ECPT results of the pre and post treatment shown in Fig. 4 were compared and factor of safety against liquefaction was computed. Both the spacings were found satisfying the target safety factor of 1. Hence for the main works the 3.0 m spacing were adopted for structures less than 4 floors and 2.75m spacing were adopted for structures having more than 4 floors.

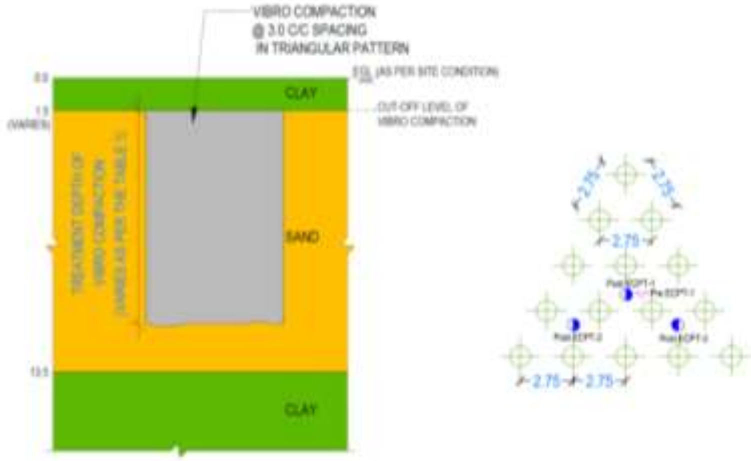

Fig. 3. Typical treatment scheme and arrangement of trial works

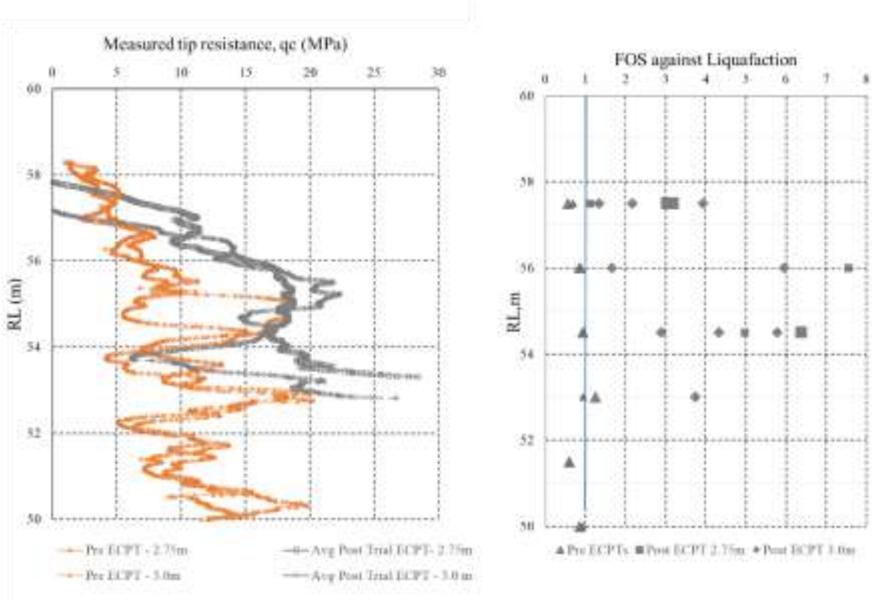

Fig. 4. Pre and post treatment ECPT results of trial works

Main works

Though the spacing of 3.0 m satisfies the requirement of liquefaction resistance, 2.75 m spacing was adopted for higher load intensity structures(>G+4) to make utilization of the additional bearing capacity contribution from the ground treatment. Apart from the main compaction points, additional rows were executed all along the periphery of each structure for lateral confinement whose extent was half the liquefying depth. The lateral confinement is mainly provided to prevent the transmission of pore water pressures from the adjacent non-treated zone.

Quality Control measures and post treatment Assessments

Effective quality control measures were being followed throughout the main works to ensure the operational parameters are in line with target criteria. The execution of vibro compaction had been monitored on real time basis with the support of M4 graphs which will provide the data of time and depth of compaction along with compaction effort of each lift as shown in Fig. 5 with which the quality of treatment shall be ensured. Further the efficacy of ground improvement had been confirmed with the support of post treatment ECPT data. Post treatment evaluation results shown in Fig. 6 clearly indicates the tip resistance plot shifts right towards the denser state and kept increasing with depth, thus the factor of safety against liquefaction is greater than 1 at all depths.

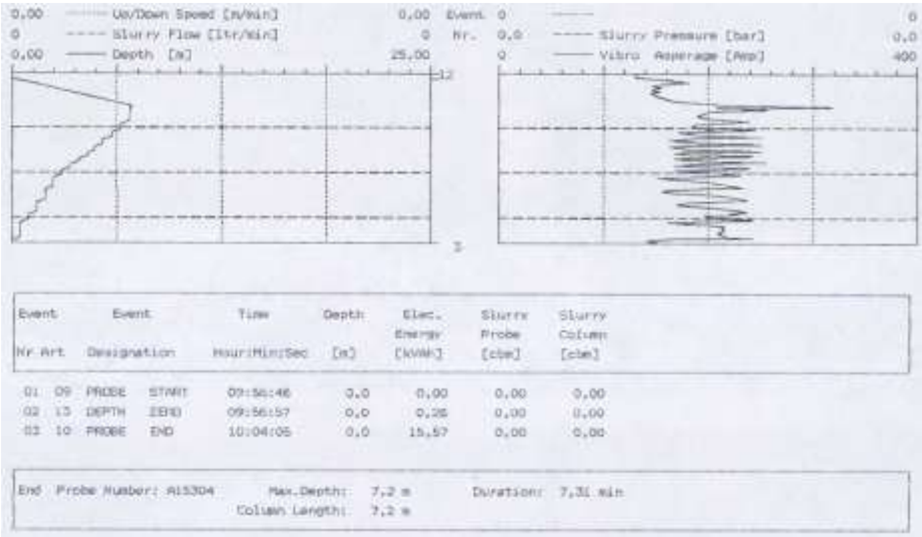

Fig. 5. Typical M4 Graph

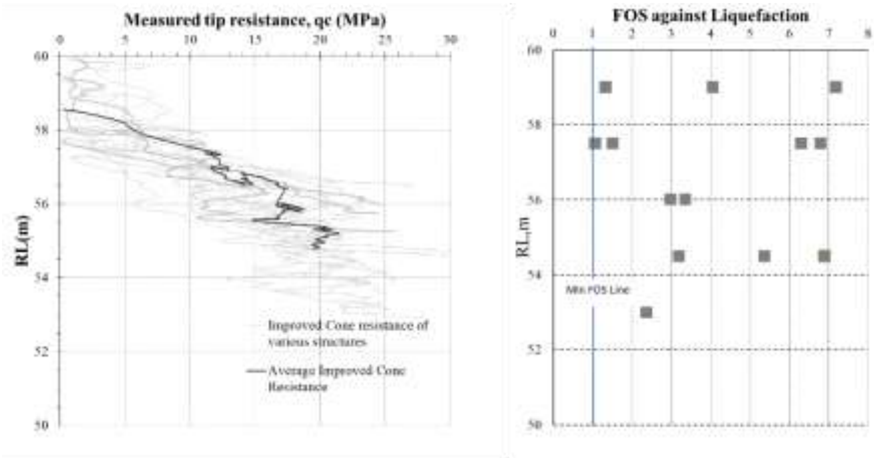

Fig. 6. Post treatment evaluation of VC works

The compaction process causes subsidence of ground in the form of conical carter as shown in Fig. 7 which happens mainly due to the reduction of void ratio caused by the reorientation of the particles towards denser configuration. Suitable backfill material (sand) had been continuously fed from the ground level to compensate the subsidence volume due to compaction. The sand compensation volume came around 12% of the overall treatment volume which once again emphasis on the quality of compaction works executed.

Fig. 7. Depth vibrator in action & Subsidence in the form of conical carter due to compaction

3.4 Advantageous foundation solution

The liquefaction phenomenon is independent of the loads acting upon the ground. Hence irrespective of type and load of structures the ground needs to be treated for liquefaction till the required depth. However, during the time of budgeting the cost implication due to liquefaction was not captured and the pile foundation was the proposed system for structures with more than 4 floors (loading intensity > 120 kPa). The liquefaction mitigation by vibro compaction densifies the soil surrounding the vibrating probe which reflects in the improved shear parameter (friction angle) of the insitu soil. This emanates as an added advantage of obtaining the treated ground with enhanced bearing capacity which would be ample to propose open foundation as an alternate to piling which saves considerable amount cost and time. In terms of production the vibro compaction works saves nearly 60%-75% of construction time and accounts for 25% - 30% savings in cost.

4 Conclusion

The encountered soil conditions pose threat to liquefaction. Vibro compaction was chosen as ground improvement technique, since fines contents are less than 12%. The operational parameters such as spacing and pattern of the compaction points were arrived based on the trial works. Effective quality monitoring procedures were adopted in the main works and efficacy of the compaction works were ensured by pre and post treatment cone penetration tests. The results of the post treatment found satisfactory and achieved the target factor of safety against liquefaction potential. Shallow foundations were chosen as foundation solution for low rise buildings (G+4). Vibro compaction technique proved to be the effective ground improvement option to address liquefaction mitigation, especially in cohesionless soils.

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