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Dynamic Compaction of Sandy and Silty Soils near Delhi for Liquefaction Mitigation

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Abstract. Along the DFCC alignment near Delhi, loose to medium dense sandy silts or silty sands deposits were encountered at certain stretches. The water table was also located at very shallow depths at these locations. The subsoil below the embankment was identified to possess liquefaction potential upto a depth of 8-11m from EGL. Though different compaction techniques are available to densify the soil and mitigate the liquefaction potential, the dynamic compaction technique was considered to be most effective for deep liquefiable soil deposit depths upto 11.0m from EGL.
It is pertinent to note that Delhi has inherent shortage of stone aggregates and thereby making stone columns option unviable. The vibro compaction was also not possible due to higher percentage of silts. Due to deeper depths of liquefiable soils, the surficial compactions techniques were also not considered to be effective. Looking at these facts, dynamic compaction is found quite useful, fast and cost effective to treat these soils more effectively.
A precast concrete tamper of desired weight was used for compaction. The sandy material was used to backfill the ground subsidence formed during dynamic compaction.
The spacing and number of drop points are adopted based on design approach and field trials. Field tests (standard penetration tests) carried out before and after dynamic compaction indicated that the ground improvement has been successful to the desired depth.

Keywords: dynamic; compaction; mitigate; liquefaction; improvement

1 Introduction

Ministry of Railways (MOR), Government of India has planned to construct a High axle load Dedicated Freight Corridor (DFC) covering about 3325 km on two corridors, Eastern and Western Corridors. Certain stretches in the DFC alignment near Delhi indicate presence of loose to medium dense sandy silt and silty sand deposits which are liquefying up to a depth of 8.0 to 11.0m from ground level. Figure 1 shows the location map of the DFC alignment near Delhi where subsoil was liquefying. In order to mitigate the risk of liquefaction, ground improvement by densification of the loose sandy and silty subsoil was necessary.

Fig. 1. Location map of DFCC alignment near Delhi

The current paper briefly describes the details of the ground improvement using dynamic compaction technique to create a suitable ground to support the railway embankment.

2 Subsoil Profile

The soil exploration of the present site was done at 500m interval along the railway alignment. The boreholes were terminated at refusal strata. The strata encountered are generally of sandy silt of low plasticity (ML-CL) and silty sand (SM). The variation in SPT- N values with depth of boreholes performed in liquefaction susceptible stretches is presented in Fig. 2. Ground water table was encountered at about 1.5 to 7.1 m depth below ground level in the liquefaction susceptible stretches.

As seen from Fig.2, it is evident that the field SPT-N values ranges from 5 to 20 especially in the depth range of 0.5 to 11.0 m from the ground level at this certain stretches. This indicates the loose to medium dense nature of subsoil.

3 Liquefaction Susceptibility Analysis

3.1 Methodology and design parameters

Due to presence of sandy and silty soils of low SPT -N values, shallow ground water table and level of ground shaking expected at the site due to an earthquake, it was concluded that the site had potential for liquefaction. Therefore, the liquefaction analysis was performed to determine the density of soils required to minimize the potential of liquefaction. These densities were then compared with densities of existing soils to determine the magnitude of liquefaction potential of the site and level of site improvement needed.

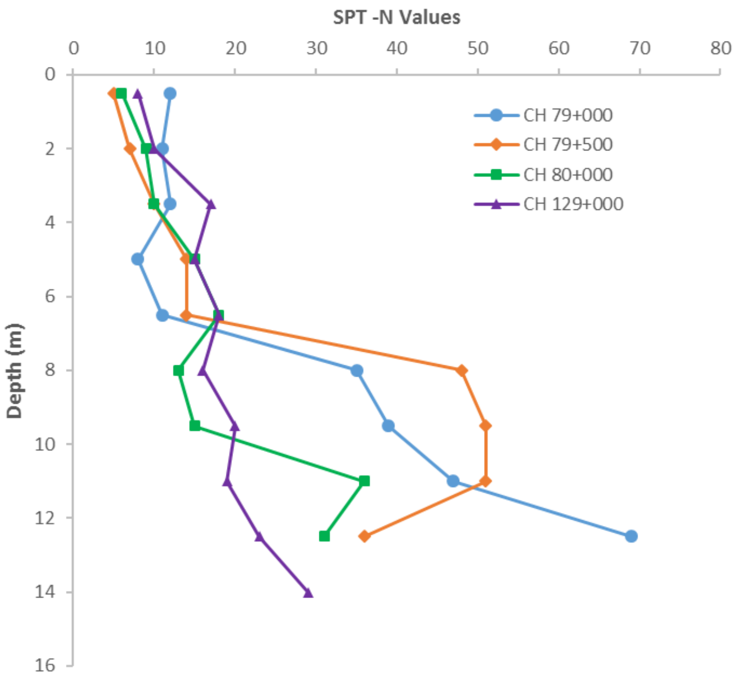

Fig. 2. SPT-N Verses Depth

According to Figure 1 and Annexure E of IS 1893 (Part1)-2016 [1] which shows the seismic zones and zone factors of important towns, the proposed site falls under Zone –IV having zone factor as 0.24. A design earthquake magnitude of 7.0 and peak ground acceleration (PGA) of 0.24g were considered in the analysis based on earthquake histories and recommended by IS 1893(Part1)-2016 [1].

The liquefaction potential calculations were carried out as per the procedure detailed in Annexure F of IS 1893 (Part1)-2016 [1]. A critical factor of safety of 1.1 was considered for the liquefaction analysis.

Two variables are required to evaluate liquefaction resistance of the soil. (1) the seismic demand on a soil and (2) the capacity of the soil to resist liquefaction. The first variable is related to the seismic load expressed as Cyclic Stress Ratio (CSR). The second variable can be related to field tests, i.e. SPT tests, CPT tests, VST tests and is expressed as CRR. For the DFCC project this variable will be calculated using SPT tests. The factor of safety follows from FOS = CRR/CSR with a correction for the magnitude of the seismic load.

Design water table is considered at ground level except for embankment stretch at CH 129+000 where water table is measured at 7.1m depth below ground level during geotechnical investigation. The design water table is considered at 4.1m depth below ground level in the analysis of stretch CH 129+00.

3.2 Results

As per the detailed liquefaction analysis, the authors estimated that the soils up to a depth of 8.0 to 11.0m from ground level are susceptible to liquefaction in the event of the design earthquake at the certain stretches of embankment. The plots of CSR, CRR and computed factor of safety against liquefaction for stretch CH 79+000 are presented in Fig. 3. The minimum required SPT -N values are calculated to achieve the required safety factor against liquefaction.

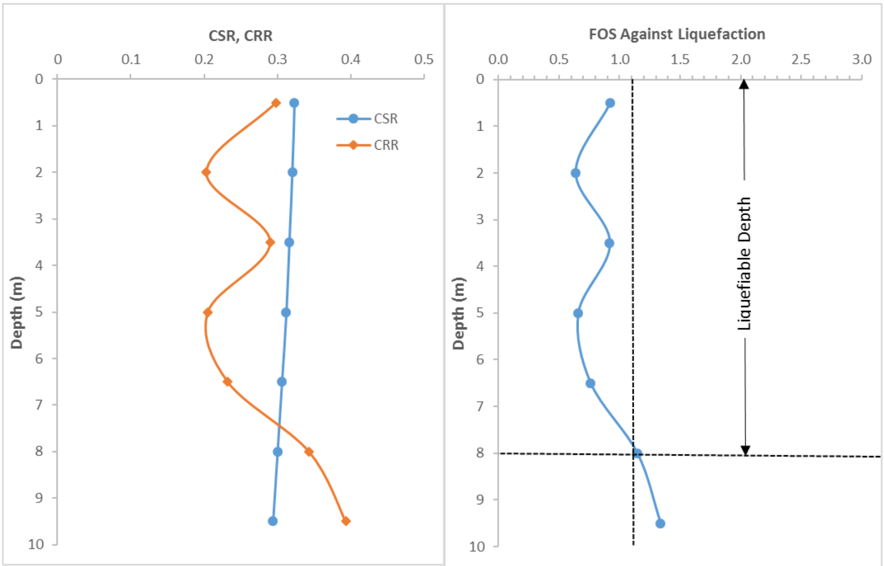

Fig. 3. Liquefaction susceptibility analysis (CH 79+000)

Densification of soils has been identified as a remedial measure against soil liquefaction due to earthquake shaking. The number of options for improving the ground were discussed and finally, after verifying the site constraints, local conditions, material availability and the cost, it was decided to use dynamic compaction technique of ground improvement.

As per IRC 75:2015, clause no. 5.2.8.1, the dynamic compaction method can be used for the densification process for sandy and silty soils to mitigate the potential risk of liquefaction.

4 Ground Improvement

4.1 Design concept

In dynamic compaction technique, the soil is densified by using a heavy drop weight. The drop weight is lifted by a crane and repeatedly dropped onto the ground surface in a grid pattern. The basic principle behind the technique consists in the transmission of high energy waves through a compressible soil layer in order to improve at depth its geotechnical properties.

As per Mitchell (1981), the depth of influence (D) up to which the ground is improved by using the tamper of weight (W) falling from the height (H) is given by:

$$D = n\sqrt{(WH)} \quad (1)$$

Where D and H are in meters and W is in tons.

n = 0.5, modification factor taken as per Mitchell (1981)

The weight of tamper (W) and height of fall (H) for the required depth of improvement (D) of 8.0m and 11.0m is calculated using equation 1 and given in Table 1.

Table 1. Required parameters of dynamic compaction

Sl. No.	Required depth of improvement (m)	Weight of tamper (Tons)	Height of fall (m)
1	8.0	30.0	9.0
2	11.0	30.0	16.5

4.2 Site execution

The dynamic compaction was done in two phases, followed by a levelling phase. The energy was applied to the soil in phases on a grid pattern over the entire area in two phases. The proposed arrangement and spacing of dynamic compaction points is given in Fig. 4.

The depth of improvement generally depends on the total amount of energy applied to the soil, which is a function of the weight of the tamper and the drop height. At each point on a 4m×4m grid, a 30-ton tamper was dropped repeatedly from a height of 9.0m and 16.5m for depth of improvement of 8.0m and 11.0m respectively. Spacing of drop points is commonly selected to be 1.5–2.5 times the diameter or width of a tamper. Usually, 7 or more blows were applied at each point and craters of about 0.5 to 1.0 m depth were formed. The square tamper, 1.84 m high, 2.4 m in width and weighing 30 tons, was made of concrete with steel casing. The in-place soils below depth of craters are compacted due to vibrations and dissipation of excessive pore pressures generated during compaction. Fig. 5 and 6 shows the dynamic compaction in progress at the grid points and resulting crater.

The resources used for the execution of dynamic compaction.

a) Friction crane – 200 ton capacity
b) Concrete tamper – 30 ton weight
c) Sling and D-Shackle

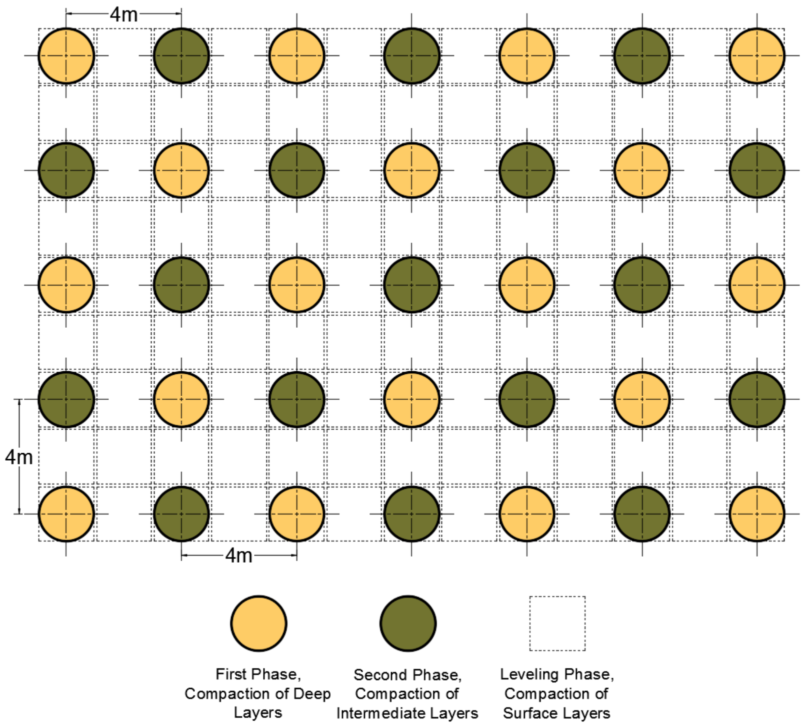

Fig. 4. Arrangement of Dynamic Compaction Grid

Fig. 5. Dynamic compaction at the site in progress

After the dynamic compaction, the area was levelled and compacted with an 8-ton vibratory roller. A minimum lag time of one week was given between each subsequent pass to allow the excess pore water pressures to dissipate.

Fig. 6. Dynamic compaction at the site in progress

5 Field Testing and Improvement

Following the area-wide dynamic compaction, standard penetration tests were conducted at predetermined locations. Fig. 7, 8 and 9 present a typical comparison of SPT-N values in a borehole before and after dynamic compaction. It is observed from Fig. 7, 8 and 9 that the SPT-N values show a substantial improvement after area-wide dynamic compaction because of the interlocking of the soil grains as a result of densification.

Fig. 7, 8 and 9 also shows N-values required to mitigate the liquefaction potential. As can be seen from Fig. 7, 8 and 9 that most of the N-values measured post improvement are greater than those required to mitigate the liquefaction potential.

6 Conclusions

Liquefaction analyses performed for a railway embankment site near Delhi are presented. The liquefaction analysis showed that the existing soils at the site had significant liquefaction potential. The site soils were densified using dynamic compaction technique. Based on the results of this investigation, the following conclusions can be drawn.

1. The dynamic compaction was effectively used to compact the sandy and silty subsoils up to 11.0m depth below ground level.
2. The compaction achieved was adequate to mitigate the liquefaction potential of the subsoils at the site.
3. In seismic zones with liquefiable soils, dynamic compaction technique provides technically sound and cost-effective solution.

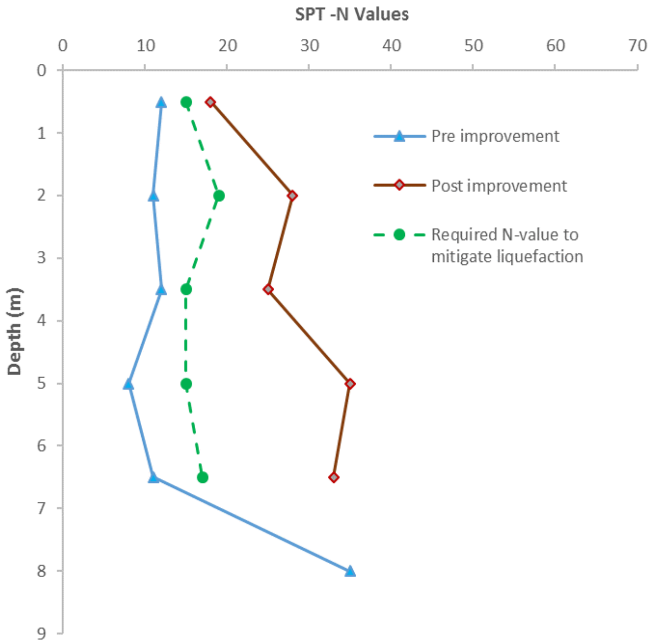

Fig. 7. SPT data before and after compaction (CH 79+000)

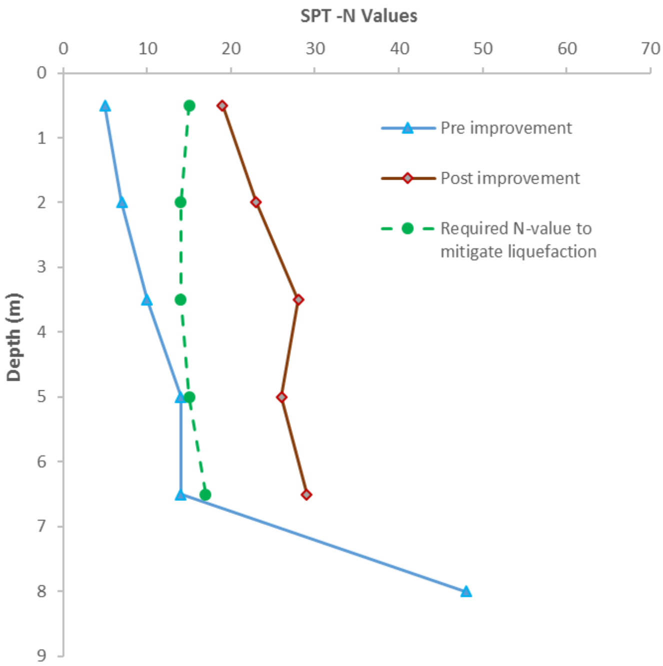

Fig. 8. SPT data before and after compaction (CH 79+500)

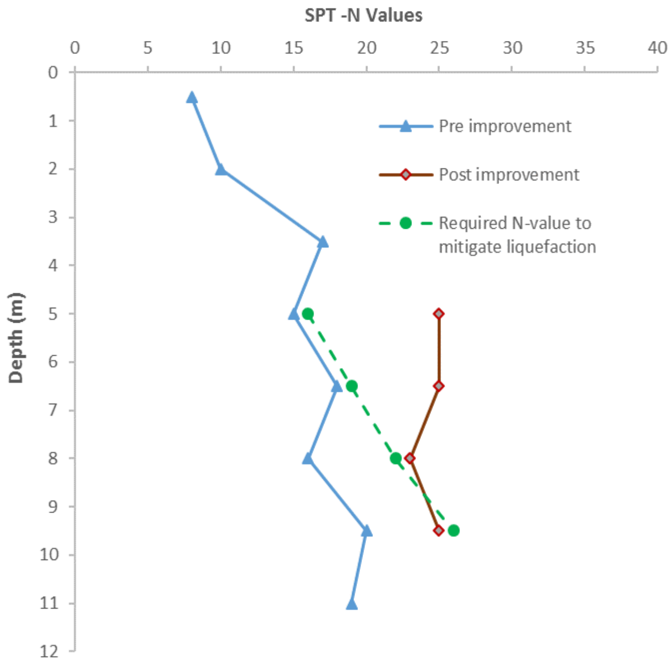

Fig. 9. SPT data before and after compaction (CH 129+000)

References

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