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Dynamic Compraction to Mitigate Liquefaction Potential

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ABSTRACT

*At a project site in Greater Noida (U.P.), loose to medium dense '*clean*' Yamuna sands were encountered, which were found to be susceptible to liquefaction to about 8-12 m depth. Dynamic compaction was carried out across the entire site to densify the soils and mitigate the risk of liquefaction. Field tests (including standard penetration tests and static cone penetration tests) carried out before and after dynamic compaction indicated that the ground improvement has been successful to the desired depth. Open foundations bearing on the improved ground could now be provided in place of piles, resulting in enormous cost-saving for the owner.*

1. INTRODUCTION

Construction for a major University project spanning an area of over 500 acres is underway at Greater Noida, Uttar Pradesh. The campus, once established, shall boast of over 84,000 m^2 of constructed area with 30 percent green cover. The site is located in the Yamuna flood plain, about 2 km. from the river (Fig. 1).

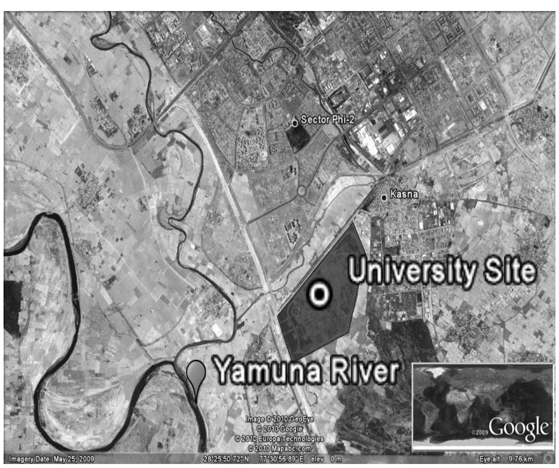


Fig. 1: Site Vicinity Map

Geotechnical investigations carried out at the project site indicated the presence of liquefiable soils to about 8-12 m depth. In order to mitigate the risk of liquefaction, ground improvement by densification of the loose sand was necessary. This paper presents the details of ground improvement by dynamic compaction adopted at the Faculty Block building, together with field test results before and after the improvement.

2. GENERAL SITE CONDITIONS

Geological Setting

The soils at the project site belong to the "*Indo-Gangetic Alluvium*" and are river deposits of the Yamuna and its tributaries. The Pleistocene and Recent Deposits of the Indo-Gangetic Basin (Krishnan, 1986) are composed of gravels, sands, silts and clays. The newer alluvium, deposited in the areas close to the river, locally called "*Khadar*", consists primarily of fine sand that is often loose in condition to about 8-12 m depth.

Scope of Investigation

The geotechnical investigation program executed at the project site includes drilling of over 600 boreholes and conducting more than 150 static cone penetration tests (SCPT) at the various structure locations.

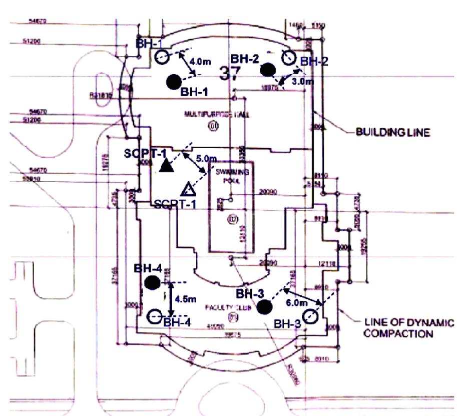


Fig. 2: Site Layout Plan

The depth of liquefiable soils at each structure location was assessed based on Standard Penetration Test (SPT) and SCPT data. Boreholes and SCPT were also carried out at the site after dynamic compaction to confirm the extent of improvement achieved and to provide data for foundation analysis.

This paper focuses on the investigations carried out at the Faculty Block building. Four boreholes of 15 m depth and one SCPT were conducted at this structure location before and after dynamic compaction, as illustrated on Figure 2.

Site Stratigraphy

The soils at the site classify primarily as sandy silt / clayey silt to about 2~3 m depth, underlain by fine sand to about 15 m depth (Fig. 3). The fines content of the sand stratum ranged from 5 to 10 percent. Groundwater was encountered at about 4~5 m depth.

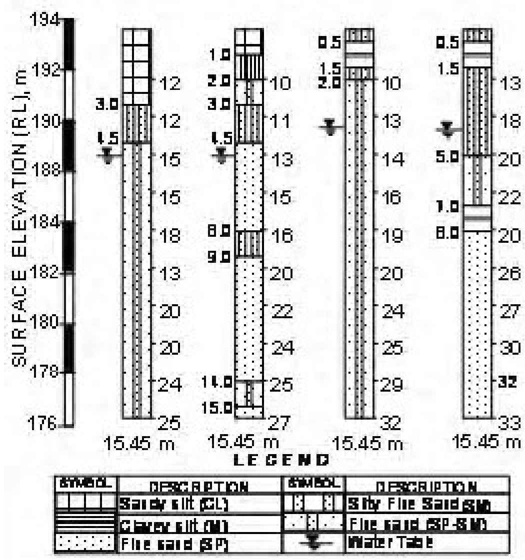


Fig. 3: Subsurface Profile

3. LIQUEFACTION SUSCEPTIBILITY ANALYSIS

Methodology and Design Parameters

As per the seismic zoning map of India (IS:1893-2002, Part 1), the project site is located in Earthquake Zone-IV.

A detailed study was carried out to assess the liquefaction potential at the site (Gupta et. al. 2008). The methodology is based on the simplified procedure developed by Seed & Idriss (1971), as described in the NCEER Summary Report (1971). A design earthquake magnitude of 6.7 and peak ground acceleration (PGA) of 0.24 g were considered to represent the Maximum Credible Earthquake (MCE) at the project location.

To avoid the difficulties and high costs associated with high-quality soil sampling and advanced laboratory testing at in-situ stress states for determination of cyclic resistance ratio (CRR), field tests consisting of SPT and SCPT were carried.

Results

Based on the project specifications, a critical factor of safety of 1.0 was considered for the liquefaction analysis. As per the detailed liquefaction analysis, the authors estimated that the soils to a depth of 8 m may be susceptible to liquefaction in the event of the design earthquake at the Faculty Block building (Fig. 7).

4. GROUND IMPROVEMENT

Out of the various methods available for densification of cohesionless soils, dynamic compaction was adopted at the project site. Initial field trials were carried out in the university areas, which demonstrated substantial improvement.

Figure 4 shows the conventional crane (TLC 955A) and the pounder used for performing the dynamic compaction.

Fig. 4: Dynamic Compaction in Progress on Site

Design Concept

In dynamic compaction, a ponder is repeatedly dropped on the ground surface from a specified height. The shock waves and high stresses induced by dropping the pounder result in the soil being compressed, together with partial liquefaction of the soil and the creation of preferential drainage paths through which pore water can be dissipated. Several drops or poundings carried out in phases are required to achieve the desired improvement.

The maximum depth of improvement (D_f) at the project site was estimated using the following expression (Mitchell & Katti, 1981):

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

where n = modification factor (taken as 0.7), W = weight of pounder, and H = height of drop (Fig. 5)

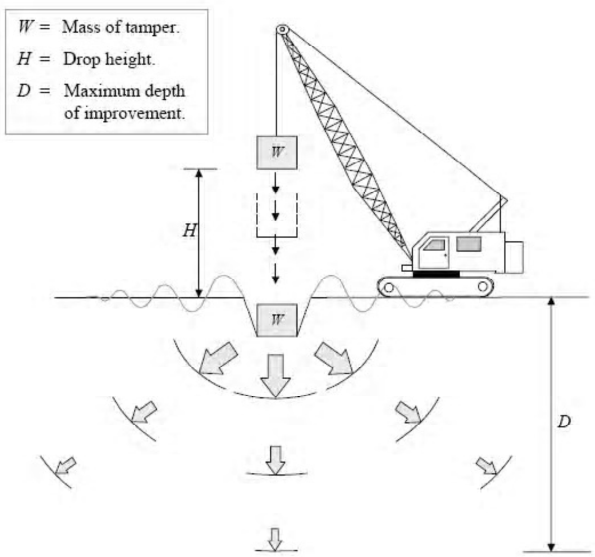


Fig. 5: Conceptual Illustration of Deep Dynamic Compaction. (*Adapted from Lukas 1995*)

At the Faculty Block building site, the contractor used a 114.3 kN pounder falling from a height of 14 m. As per Eq. (1), the corresponding (theoretical) depth of improvement works out as 9 m.

Site Execution

The dynamic compaction was done in two phases, followed by an ironing phase.

At each point on a 4 m x 4 m grid, a pounder of 114.3 kN was dropped repeatedly from a height of 14 m, i.e. an input energy of 1600 kN.m was applied. Usually, 10 or more blows were applied at each point and craters of about 1.0 to 1.5 m depth were formed. Certain amount of heave was also observed around the craters. The volume of the craters was measured and recorded before they were backfilled with GSB Grade II.

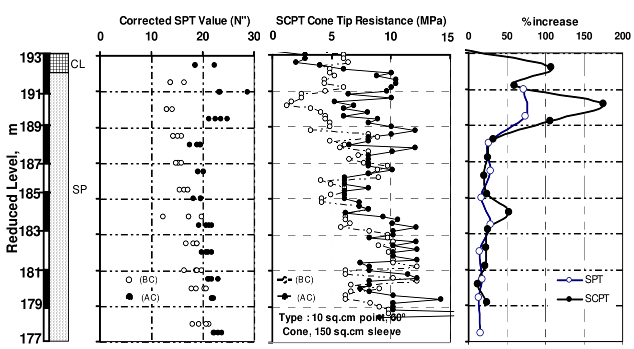


Fig. 6: SPT and SCPT Before and After Compaction

The second pass also involved the same treatment on a grid offset by 2.0 m from the original grid. This was followed by an ironing pass involving general tamping of the ground with a reduced fall of 6 m for obtaining a level surface on the finished ground. The average total energy input applied considering all the passes was 2214 kN.m/m^2.

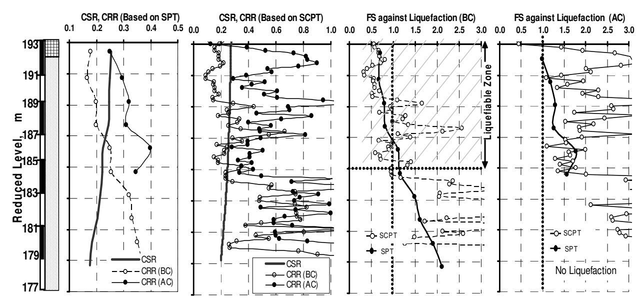
After dynamic compaction was done, the area was graded with ten passes of a 10 tonne vibratory roller. A minimum lag time of one week was given between each subsequent pass to allow the excess pore pressures to dissipate.

5. IMPROVEMENT ACHIEVED

Sufficient relaxation time was given to allow pore pressures to dissipate. A second geotechnical investigation was then done to assess the extent of improvement achieved. The scope of this investigation at the Faculty Block building includes four boreholes and one SCPT, as illustrated on Figure 2.

Soil Densification

A plot of SPT and SCPT values before and after dynamic compaction is presented on Figure 6. The test results are also presented in terms of average % increase in the values against original values before treatment.



* BC = Before Compaction, AC = After Compaction

Fig. 7: Liquefaction Susceptibility Analysis Before and After Compaction

It can be seen that there is a 75% improvement in the corrected SPT values (N") to about 4 m depth, and 25% to 30% increase to about 10 m depth. SPT values after compaction are generally greater than 20. The improvement in cone resistance values (q_c) varies widely from 50% to 170% in the top 4 m, and 25% to 50% to about 10 m depth. Cone resistance values after compaction are generally greater than 5 MPa

The peak improvement was observed between 1 m and 5 m depths. The treatment is effective up to a depth of about 8-10 m, below which the increase in SPT and cone resistance values is marginal. This is in good agreement with the maximum depth of improvement (D_f) of 9 m estimated as per Eq. (1).

Liquefaction Mitigation

Comparative plots of CSR, CRR and computed factor of safety against liquefaction (based on SPT and SCPT values) before and after compaction are presented on Figure 7.

It can be seen that the untreated site (before compaction) was susceptible to liquefaction to about 8 m depth. However, after compaction, the factor of safety against liquefaction (based on both SPT and SCPT values) is greater than 1.0. Thus, ground improvement by dynamic compaction has been successful in mitigating the liquefaction potential at the site.

Foundation Selection

For the unimproved ground, pile foundations would have been necessary to transfer the structural loads below the liquefiable zone. As a result of ground improvement by dynamic compaction, open foundations bearing on the improved ground could now be provided. This resulted in substantial time and cost savings for the owner.

Isolated column footings with interconnecting plinth beams were provided for the Faculty Block building. These foundations were designed for a net allowable bearing pressure of 175 kPa.

6. CONCLUSIONS

The paper demonstrates the successful mitigation of liquefaction potential at a project site by use of dynamic compaction. The method is successful in areas where loose sands are met. Field trials should be conducted to confirm the feasibility of the ground improvement method. Sufficient in-situ testing before and after improvement is essential to ensure that adequate compaction is achieved.

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