Proceedings of Indian Geotechnical Conference
December 13-15,2012, Delhi (Paper No. B-298)

BUILDING A MEGA POWER PLANT ON LIQUIFIABLE SANDS – A CASE STUDY

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ABSTRACT: Geotechnical investigation for a major power plant in Punjab indicated the likelihood of liquefaction of the loose sands to about 7.5-11 m depth. To mitigate the liquefaction potential, ground improvement by vibro-compaction was done for the light to medium loaded facilities. Piles extending well below the liquefiable zone were used to support heavily loaded facilities. The paper presents data and analysis for the Boiler-I area where ground improvement was done successfully done and raft foundation for the raft was provided.

INTRODUCTION

A 540 MW capacity supercritical thermal power plant is being constructed in the state of Punjab, along the banks of the Beas River. The site covers an area over 500 acres. Various facilities planned include Power House, Boiler, Cooling Tower, Chimney, ESP area, etc.

A vicinity map showing the location of the site is presented on Fig. 1.

Fig. 1 Vicinity Map

GENERAL SITE CONDITIONS

Scope of Geotechnical Investigation

The geotechnical investigations at the project site included 71 exploratory boreholes to 30 m depth, 9 cone penetration tests (CPT), 1 plate load test, 13 test pits, 6 cross-hole seismic tests, 4 field California bearing tests, 2 field permeability tests and 19 electrical resistivity tests. This paper presents data from the location of the Boiler-I.

Regional Geology

The project site is in Punjab on the banks of the Beas River. The soils at the project site belong to the "*Indo Gangetic Alluvium*" and are river deposits of the Beas and its tributaries. The Pleistocene and Recent Deposits of the Indo-Gangetic Basin [1] are composed of gravels, sands, silts and clays. The newer alluvium, deposited in the areas close to the river, is locally called "*Khadar*" and consists primarily of fine sand that is often loose in condition at shallow depths.

Site Stratigraphy

The investigations confirmed the presence of 'clean' river sands at the site to the maximum explored depth. In the Boiler-I area, Field SPT values indicated loose conditions (N<10) to about 3-5 m depth. The SPT values range from 11 to 16 to 10 m depth and from 17 to 27 to 15 m depth. Below this, SPT values range from 32 to 51 to 24 m depth and from 55 to 77 to30 m depth. Typical borehole data is presented on Fig. 2.

Groundwater was encountered at 1.9-4.3 m depth (RL 216.0~220.0 m) and may rise to ground level during rains. In view of the proximity of the site to the Beas River, the design groundwater level was taken at the ground level.

SCPT results indicate cone tip resistances (q_c) of 25 to 70 kg/cm^2 to 4.5 m depth, and 33 to 67g/cm^2 to about 10 m depth. Below this, q_c values range from 70 to 120 kg/cm^2 to 12 m depth, and meet refusal at 14-15 m depth.

Shear wave velocities (V_s) are less than 200-220 m/s to about 10 m depth and increase gradually with depth. Fig. 3 presents plots of corrected SPT values, qc values and P & S wave velocities with depth.

Plots of corrected SPT values, q_c and V_s with depth are presented on Fig. 3.

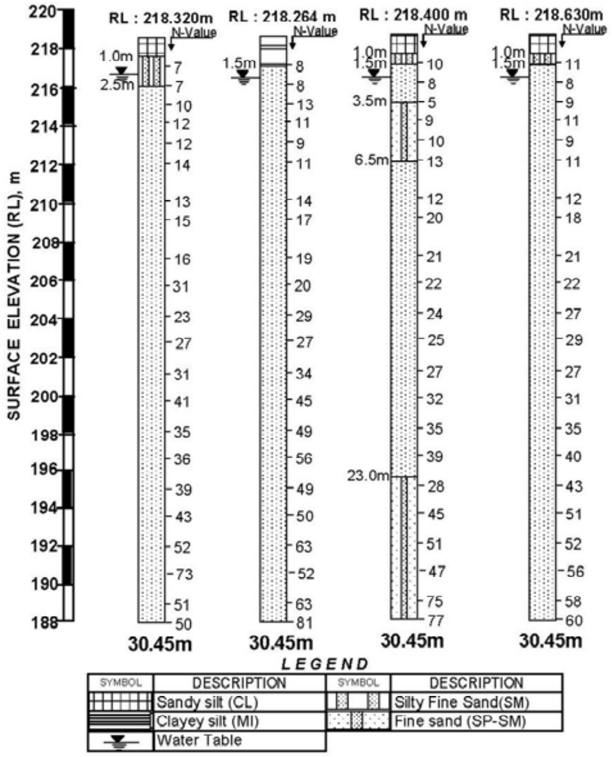

Fig. 2 Typical Borehole Data

DETAILED LIQUEFACTION ANALYSIS

A detailed liquefaction susceptibility assessment (based on SPT, CPT and shear wave velocity profiles) was done as per the simplified procedure presented in the NCEER Summary Report [2].

As per the project specifications, the analysis was done for an earthquake magnitude of 6.7 and a peak ground acceleration of 0.24 g. Fig. 3 presents typical results of our analysis.

As per the analysis, the computed depth of liquefaction varied from 9 m to 11.5 m (RL 208.4 m to RL 210.0 m) across the site. In the Boiler-I area, the depth of liquefaction was estimated as 10 m.

Fig 4 presents the cyclic stress ratio (CSR) and cyclic resistance ratio with depth based on SPT, qc and V_s versus depth together with the safety factor against liquefaction.

ENGINEERING SOLUTIONS

In view of the liquefaction potential, it is not feasible to support the power plant facilities on the natural soils. To densify the soils, extensive ground improvement was carried out by vibro-compaction method in order to mitigate the liquefaction potential and justify the use of open foundations.

Structures such as the TG, Chimney, etc. are very heavily loaded. It was decided to support these structures on deep piles extending well below the liquefiable zone.

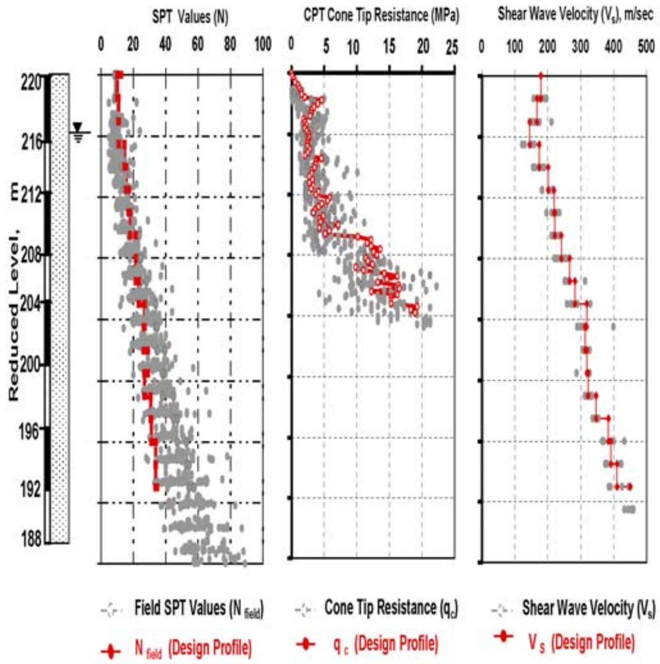

Fig. 3 SPT, q_c and S Wave velocities profile

Ground Improvement

Ground improvement was done by vibro-compaction. The vibro-probe was inserted into the ground and penetrated to about 10-12 m depth. A water jet was used to assist the densification process. The depression formed by the compaction process was filled with sand and compacted using a 10 ton vibratory roller.

Fig. 5 presents a photograph of the vibro-compaction in progress.

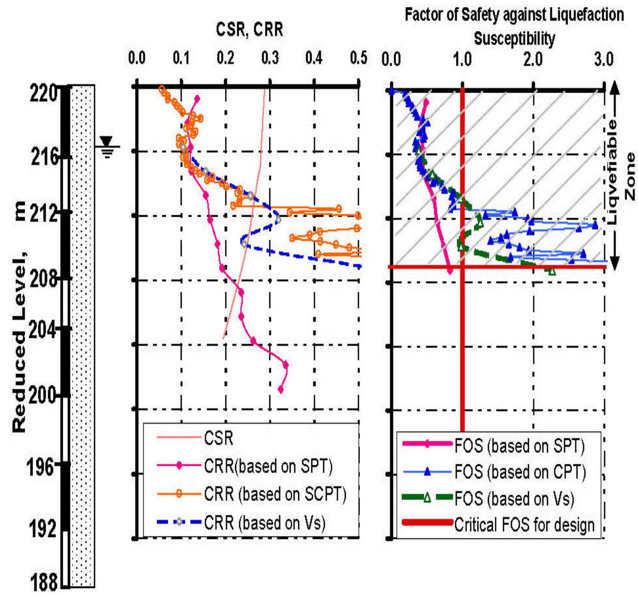

Fig. 4 CSR, CSR and Factor of Safety against Liquefaction

Fig. 5 Vibro-compaction in progress

Extent of Improvement Achieved
The vibro-compaction was successful in densifying the loose sands and to mitigate the liquefaction potential. There was substantial increase in the SPT and q_c values. Fig 6 presents the N values and qc values before and after the compaction process.

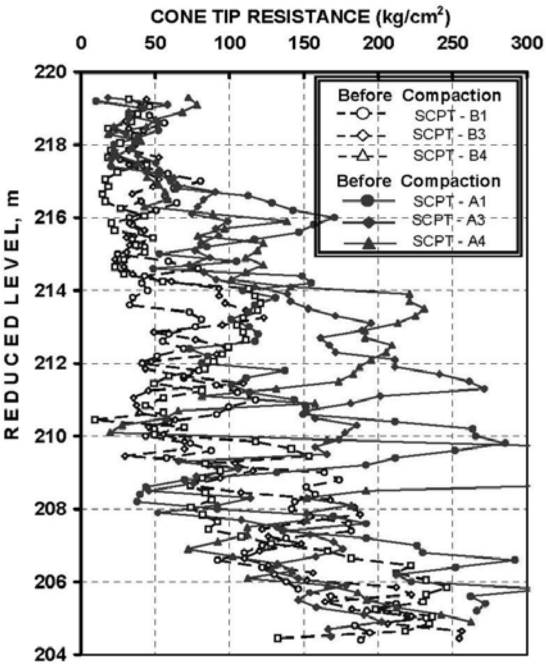

Fig. 6 Cone tip resistance before and after compaction (Boiler-I)

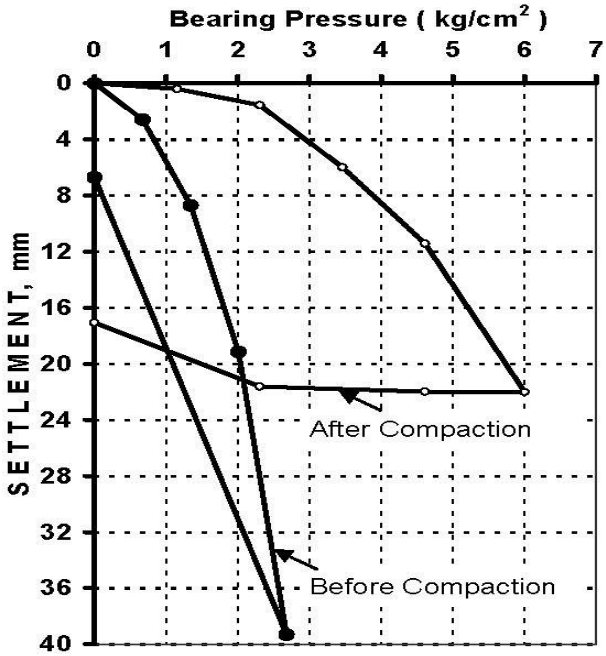

Fig. 7 Plate Load Tests before and after compaction

Results of plate load tests conducted on a 60 x 60 cm size test plate before and after compaction are illustrated on Fig. 7.

The test results indicate substantial improvement after the compaction process, the liquefaction potential has been successfully mitigated. Analysis for liquefaction potential after the densification process confirmed factor of safety exceeding 1.2 thereby confirming that the soils shall not experience liquefaction under the design earthquake.

After the compaction was done, a vibratory roller was used to compact the soils at the founding level. Raft foundation for the boiler was constructed at 2 m depth. The foundation was designed for a net allowable bearing pressure of 220 kPa for a permissible total settlement of 25 mm.

Pile Foundations
RCC bored cast-in situ piles were used to support very heavily loaded facilities such as TG, Chimney, etc. The pile capacity analysis was done ignoring the skin friction in the top 10 m of soil that is prone to liquefaction. The calculations were done in accordance with IS: 2911 Part 1 Section 2 and include a factor of safety of 2.5.

Table-1 presents the safe compressive and pullout capacities used for design of 600 mm diameter RCC bored cast-in-situ piles with cut-off level at 3.5 m depth below the ground level:

Table 1: Safe Pile Capacities ignoring skin friction in Liquefiable zone

Pile length below COL, m	Safe Pile Capacity, Tonnes	
	Compression	Pullout
20	83	27
23	95	33
26	108	39

The test load for pile load test was worked out considering the skin friction in te top 10 m so as to simulate the normal condition. However, the safe load for design was restricted to the values given in Table 1 so as to ensure that the piles are safe during earthquake.

CONCLUDING REMARKS

The construction of the heavily loaded facilities of the mega power plant was done after thorough evaluation of the geotechnical data. Detailed analysis indicated the potential for liquefaction. The ground improvement by vibro-compaction could successfully mitigate the liquefaction potential and also ensure a high safe bearing capacity for design of the structures. Piles were used in areas where the loadings were very heavy.

ACKNOWLEDGEMENTS

The authors are grateful to M/s. Punj Lloyd Ltd. and GVK Power Ltd. for giving Cengrs Geotechnica Pvt. Ltd. an opportunity to perform the investigation and the detailed liquefaction studies as well as tests before and after improvement.

REFERENCES

1. Krishnan, M. (2008), *Geosynthetics Practices*, 3rd Ed., Prentice Hall, New Delhi, India.
2. Youd, T.L., and Idriss, I.M., (2001), "Liquefaction Resistance of Soils: Summary Report from the 1996 NCEER and 1998 NCEER/NSF Workshops on Evaluation of Liquefaction Resistance of Soils", Jl of Geotech and Geoenv Engineering, April 2001, pp. 297-313.