Vibroflotation for Ground Improvement — A Case Study

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SYNOPSIS A case study concerning the adoption of vibroflotation technique in a loosely filled up granular soil has been presented. The technical feasibility of the process of compaction has been established before execution of the work and the post compaction process consisted of monitoring the work by plate load tests and static cone penetration tests. The settlements of the foundations resting on the compacted granular soil have been monitored and they are well within the permissible limits. Hence this technique of compaction has been proved to be economical when compared to the adoption of deep foundation, like, the pile foundation.

INTRODUCTION

Very often, foundation engineers have been confronted with field situations wherein, heavily loaded structures have to be founded on weak soils. The conventional pile foundations in many cases are not economical, hence the need of ground improvement. Vibroflotation is one such important method which has been successfully adopted in India, during the last two decades (Krishnamurthy et al, 1983). This technique has been adopted earlier for tank foundations in oil refineries, however, they are now extended to industrial structures also, depending on the nature of the sub-soil.

In this investigation, a case history has been presented pertaining to the adoption of vibroflotation technique, for compacting a very loosely filled up granular soil in the area around the Mangalore Chemicals and Fertilizers Company Limited, Mangalore, INdia, situated on the West Coast of India (Fig.1)

SUB-SOIL CONDITIONS

The area in which the present fertilizer company is located, was originally consisted of agricultural land with an average level of 1.8m above the mean sea level. There were a few natural drainage channels and some lakes. In the year 1966, this area was raised by dredged soil obtained during the construction of one of the major ports of India, namely, the New Mangalore Port. The dredged material consisted of two layers, out of which, the upper layer was clean sand and the lower layer clay. The extent of clay deposit varies widely throughout the site.

Penetration Tests

The sub-soil in the area was investigated by bore holes with penetration tests, namely, Standard Penetration and Cone Penetration tests. Standard penetration tests (SPT) were conducted at regular intervals during the bore hole investigation. In addition, laboratory tests were also conducted on both disturbed and un-disturbed samples, obtained from the bore holes, for grain size analysis, consolidation tests etc. The presence of marine clay was identified with a consistency ranging from very soft to stiff. A typical bore hole chart of the area is illustrated in Fig.2 showing the various strata met with and its classification and the N values plotted along the depth. The N value varied from 1 to 18 in a depth of 18m. Rock was available at depths ranging from 28m to 30m.

TYPE OF FOUNDATION

From the above soil profile, it was noted that no shallow foundation could be directly supported on the ground without resorting to some sub-soil improvement. Further, the company insisted that piles (bearing piles) cannot be driven up to the rock as this process will cause great disturbance to the machines which have been already installed in the areas nearby this site. This condition posed a serious challenge and therefore necessiated the adoption of a suitable ground improvement technique, to improve the bearing capacity of the sub-soil to enable shallow footings to be adopted for the machines which are proposed to be installed in this area.

Bored Compaction Piles

An attempt was also made to adopt bored compaction piles to improve the bearing

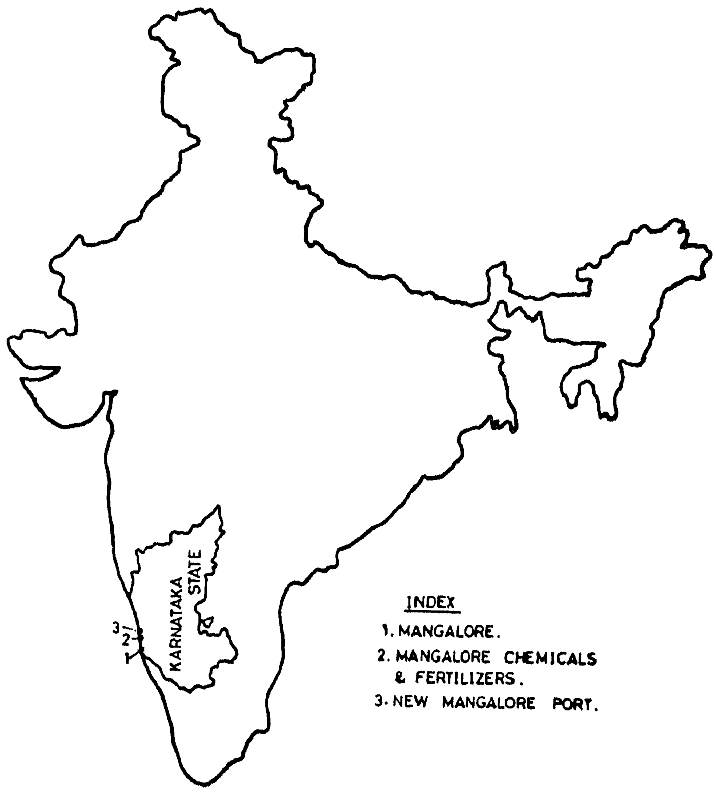

Fig.1. Map showing LOcation of Site in INDIA.

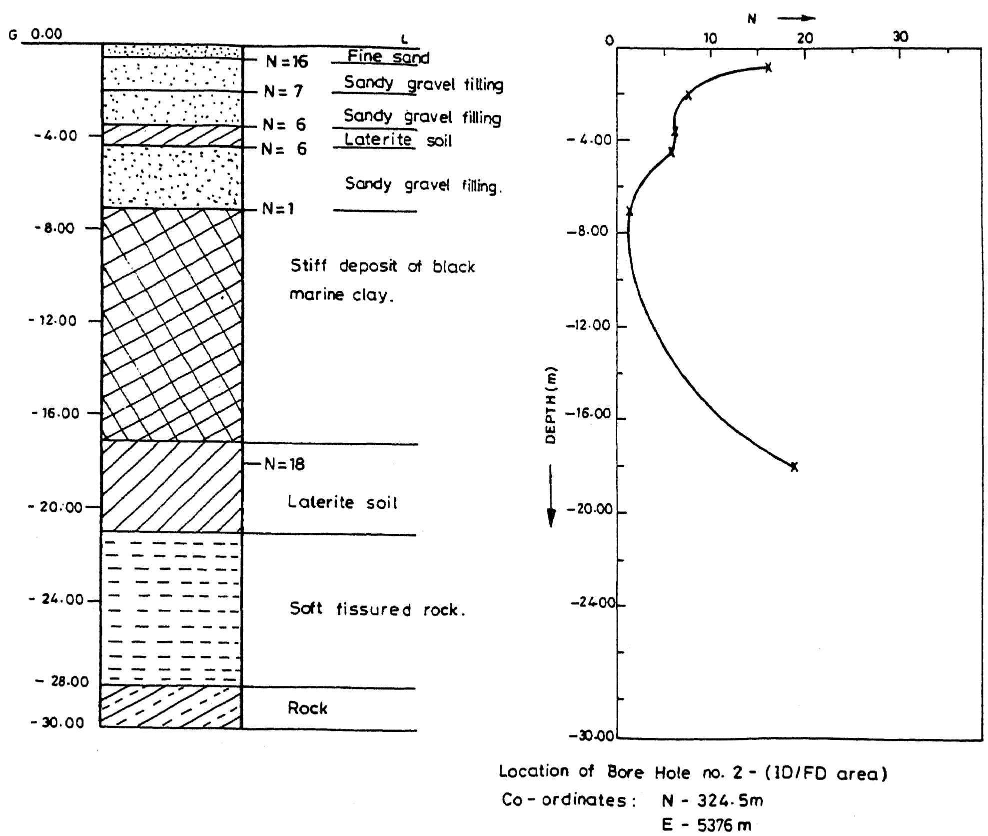

Fig.2. Typical Bore Hole Chart.

capacity but this method was not successful because of certain difficulties met with during the construction of the pile and also during the load test. Hence this method was not found to be feasible.

Loads on the Foundation

The expected loads from the machines which are to be installed in the proposed area were estimated to be in the range of 200 to 250 kN/m^2.

TECHNICAL FEASIBILITY

Before execution of this work, it was necessary to examine the technical feasibility of the vibroflotation process. Ideal soils suitable for this technique are cohesionless soils and gravels with a maximum of 10% of their particles, passing through No.200 sieve, size 0.074mm, (Koerner, 1985). However, it has been found that vibroflotation can also be adopted in silty or clayey soils containing upto 25% of silt or 5% of clay (Tomlinson, 1973). Therefore, the next point under consideration was whether vibroflotation will be really technically feasible or not. For this it was necessary to ascertain whether the sandy soil available at higher depths will be suitable for improvement by vibroflotation. A detailed analysis of the sandy soils was undertaken to determine the percentage of silt and clay in the sand. It was found from the grain size analysis (Fig.3) that the percentage of silt and clay was less than 10% and hence the sandy soils were ideally suitable for compaction by vibroflotation.

AREA FOR VIBROFLOATATION

The proposed area, measuring, 24mx6m, for compaction using vibrofloatation, was divided into suitable grids of 2mx2m and the desired depth of compaction was around 7m.

Execution of Work

The work was awarded to M/s. CEM-INDIA, a construction company of Bombay, India and the contract provided the following criteria for acceptance.

1. Settlement on a 1.8m diameter plate on a single vibropoint under a pressure of 450 kN/m^2 shall be less than 12mm.

2. SCPT cone resistance of atleast 1500N/cm^2 shall be achieved in the sandy strata, after compaction.

M/s. CEM-INDIA adopted the wet process using a standard vibrofloat, 400mm diameter 2m long and weighing 30 kN. The vibrating unit was put down to the required depth at intervals of 2m centre to centre, longitudinally and breadthwise of the area, so as to form a grid of 2mx2m. The unit was withdrawn in 0.25m stages, vibration being applied at each stage and ground surface made up as required. The unit was put down again at 2m away and the process repeated until the whole area to be treated was covered by overlapping of cylinders of compacted soil.

Comparison of SPT

A comparison of the SPT conducted both before and after vibrofloatation has been illustrated in Fig.4. It can be seen from the above comparison that vibrofloatation considerably increases the 'N' values.

POST COMPACTION PROCESS

The post compaction process consisted of monitoring the work by plate load tests and static cone penetration tests, using a 100 kN machine. The test loading plate of 1.8m diameter completely covers the zone of influence of the vibropoint. Five out of eight plate load tests conducted gave a settlement of 12mm or less at a test load of 1150 kN. Two tests showed a settlement of less than 15mm while in one test, the settlement was 40mm. Typical load-settlement curves are illustrated in Fig.5. The load-settlement curves clearly indicate the improvement of load carrying capacity with surcharge. It was generally noted that the settlement was less than 10mm in the range of the working loads of 250 kN/m^2.

Static Cone Resistance

Static cone resistance of 1500 N/cm^2 in sand was generally achieved in almost all the cases. Typical/record of SCPT are shown in Fig.6. Static cone penetration tests made before and after compaction showed a threefold to fivefold increase in the cone resistance, between the depths of 2m to 7m.

FOUNDATION DESIGN

After confirming the increase in the bearing capacity of the soil, the foundations for the Flue gas furbine (ID FAN) and combustion Air-fan turbine (FD FAN) were designed as raft foundations, based on the static and dynamic analysis of the various loads acting on the foundations.

In order to ascertain whether the desired improvement in the compaction of the sandy soil has taken place after vibroflotation in the proposed area, the settlement of the foundations were regularly monitored and it was found to be well within the permissible limits. The machines installed on these foundations are in good working condition and absolutely free from any problems.

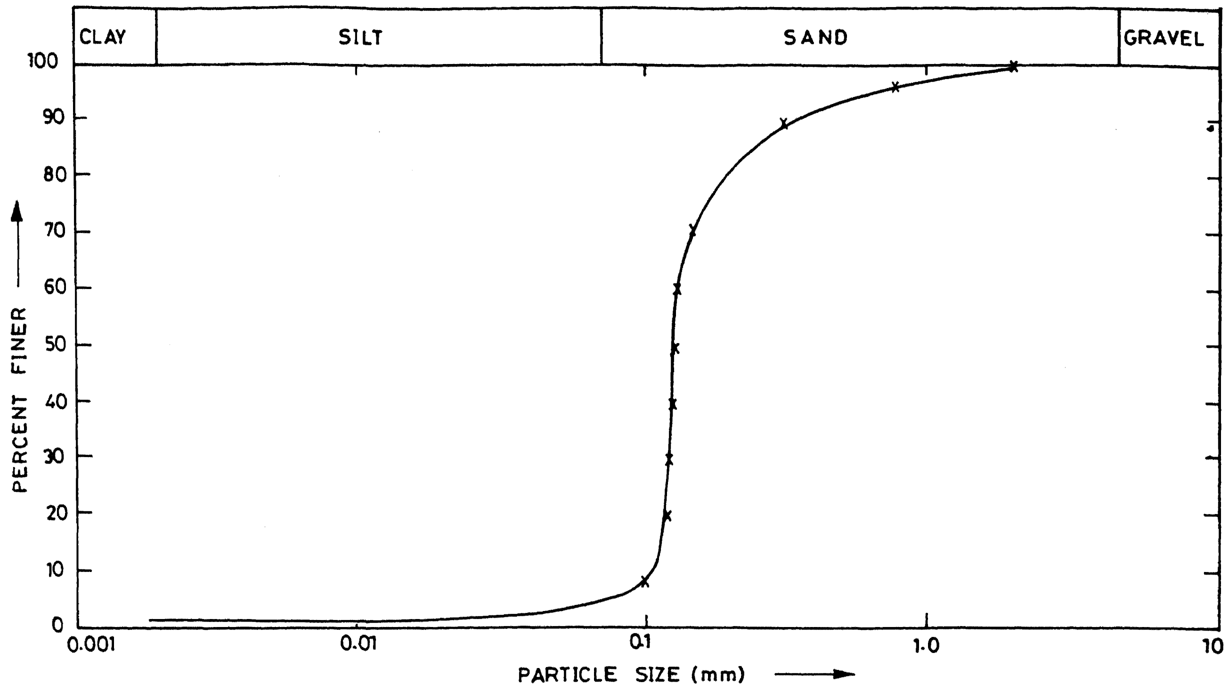

Fig.3. Grain size Analysis.

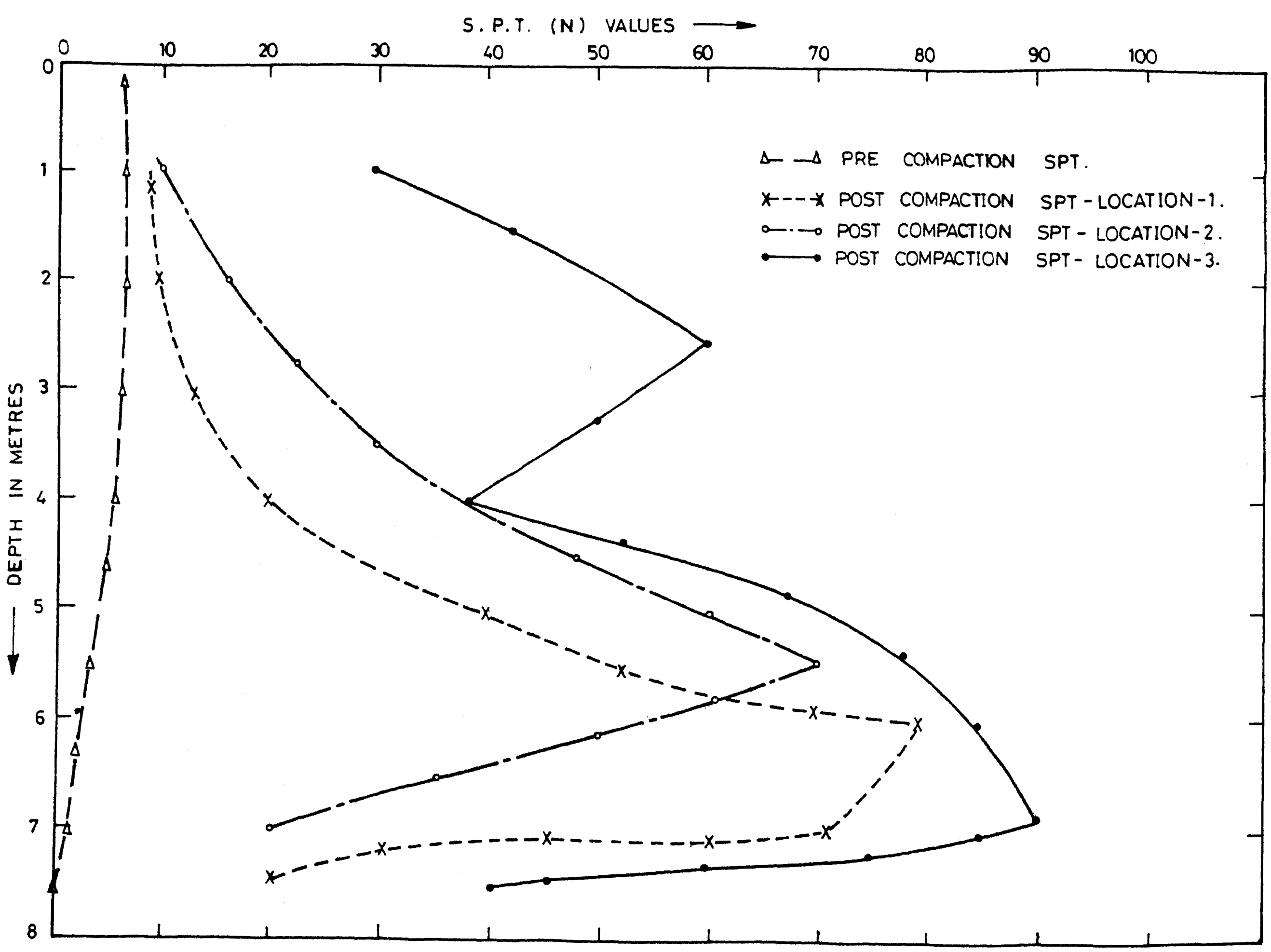

Fig.4. Comparison of N Values (SPT)

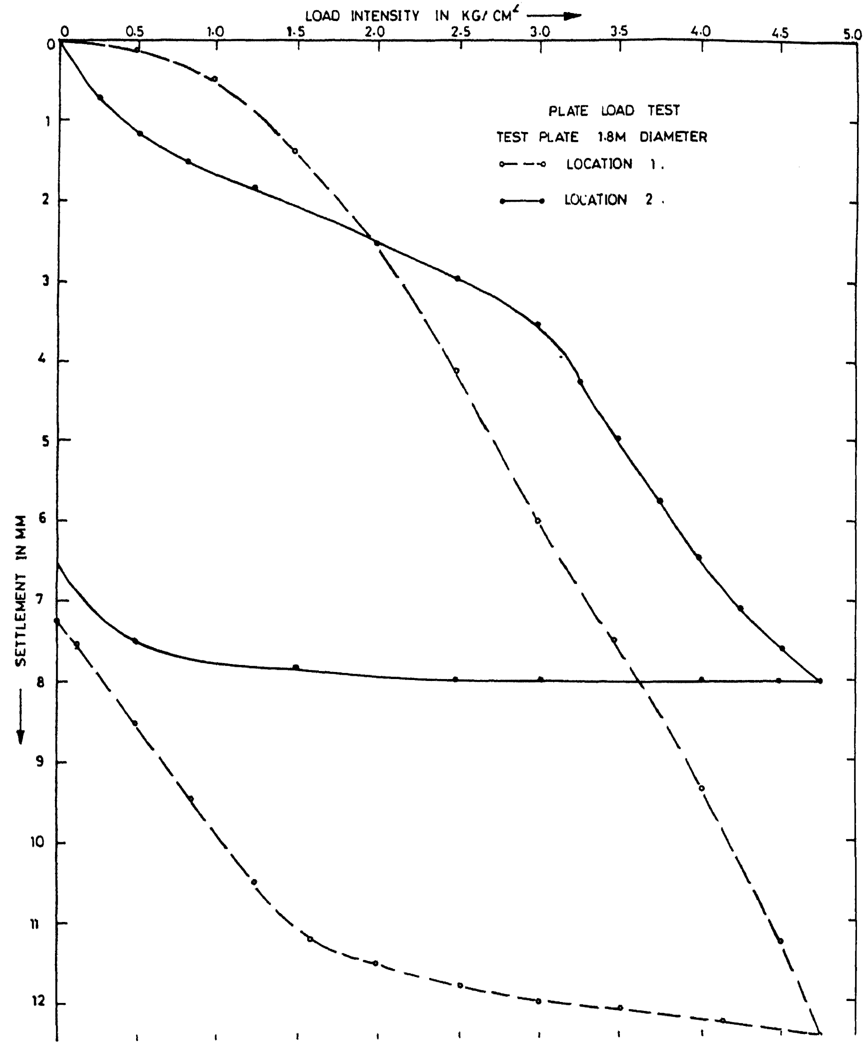

Fig.5. Load Intensity - Settlement Relationship.

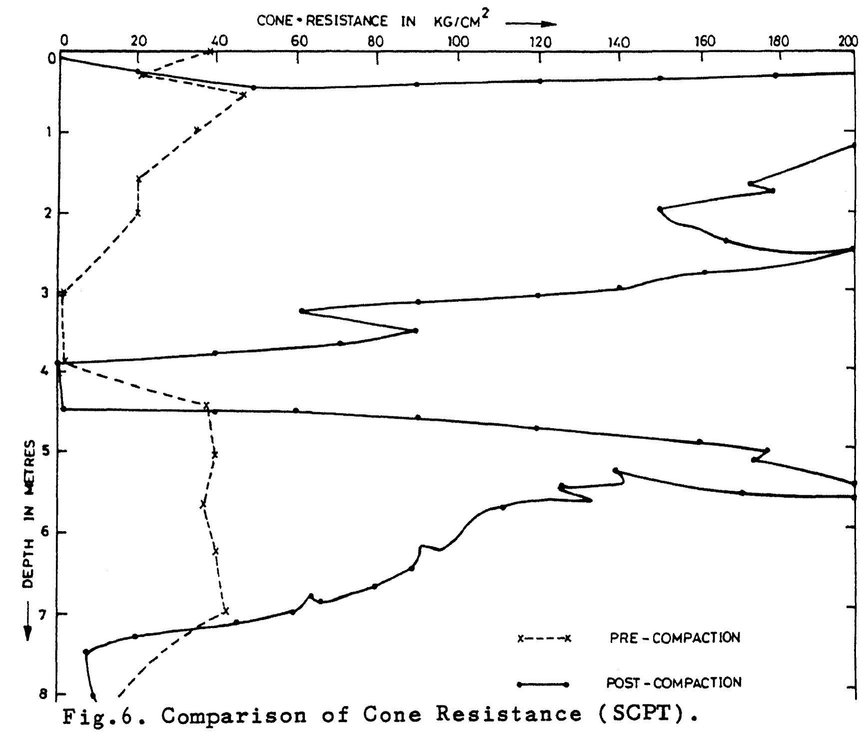

Fig.6. Comparison of Cone Resistance (SCPT).

CONCLUSIONS

A difficult case of foundations resting on loosely filled up sandy soil has been successfully solved by the adoption of vibroflotation technique for ground improvement. This technique has been found to be technically feasible as well as economical.

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