AN INVESTIGATION INTO THE LIQUEFACTION POTENTIAL AND MEASURES TAKEN TO COUNTER LIQUEFACTION UNDER REFINERY STORAGE TANKS

R.K.M. BHANDARI*

SUMMARY

Liquefaction potential analysis made by employing depth reduction factors suggested by Nishiyama et al[2] indicated likelyhood of liquefaction to 10 to 11m depth as against depths larger than 16m predicted by using Seed et al[1] factors. The latter prediction was not in conformity with the observed soil characteristics. To resist liquefaction, relative density of the subsoil was improved to 80% by compaction piles and vibroflotation. The effectiveness and limitations of these methods as well as settlement behaviour of storage tanks are presented and discussed.

INTRODUCTION

The refinery site at Bongaigaon lies in the Assam Plateau which is bordered on all sides by faults. Acute seismic activity of the north eastern region of India is borne by occurrence of world's two major earthquakes of August 15, 1950 and the great Assam earthquake of June 12, 1897. Below 0.6m thick surface layer of silty loam, the subsoils at the refinery site consisted generally of alluvial loose to moderately dense sand between depths of 0.6 to 9.20 m with water table at 1.0m below the natural ground surface. These soils were underlaid by dense to very dense sand mixed with gravels and cobbles except in the eastern part of the site where an additional stratum of firm clayey to sandy silt was present between 4.5 m to 9.5 m depth. Geologic and tectonic set up of the region is such that occurrence of foundation failures like the ones caused by liquefaction during the Niigata earthquake of 1964 can not be ruled out. To preclude catastrophe, the subsoils under the refinery tanks were improved to 80 percent relative density by vibroflotation and compaction piles.

SEISMIC AND SOIL PARAMETERS

Maximum magnitude of earthquake, its duration expressed in terms of average equivalent cycles N_{eq} and the maximum horizontal acceleration are the three basic seismic parameters. Past seismic history and the subsoils encountered at the refinery site indicated that shallow earthquakes of magnitude 7.0 with return period of 79 years are most likely to rock the site. The focal depth of the design shocks could be taken as 32 km. The most proximate potential epicentral distance is approximately 50 km. These parameters were employed to obtain the maximum horizontal acceleration of 0.38g at the site using empirical relationship[6] between acceleration and distance, magnitude and focal depth. The value of N_{eq} depends upon the duration of ground shaking and thus on the magnitude of

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*Senior Engineer, Engineering Tech. and Dev. Division
Engineers India Ltd., 4 Parliament St., New Delhi.110001, India

the earthquake. Seed et al[1] suggested N_{eq}=10 for an earthquake of magnitude 7.0.

Main soil parameters of interest are mean grain size D50 initial confining pressure as well as relative density, Dr. Appropriate laboratory tests were carried out to determine these except Dr which was estimated using relationship[2] N=25 Dr^2.

LIQUEFACTION POTENTIAL ANALYSIS

Liquefaction will occur when average equivalent shear stress, T_e, induced by earthquake is greater than the shear resistance, T_r of the soil column obtained from the laboratory tests. The accuracy of T_e depends to a great extent on the reliability of depth reduction factor, r_d, to account for the deformability of the soil column. Taking alluvial soil properties and using earthquakes of long as well as short wave contents, Nishiyama[2] calculated r_d by performing dynamic response analysis on six ground models by one wave propagation theory. This resulted in obtaining lower and significantly narrower range of r_d with respect to depth as compared to that given by Seed, refer fig 1. Employing these modified r_d factors, it is seen from fig 2 that the zone of liquefaction extends to 10 to 11m depth. The use of Seed r_d factors (reference 1, fig 4), however, resulted in a T_e curve which indicated liquefaction to depths of 16.0m. Such large liquefiable depths were not justified by the soil types encountered and the generally very dense state of compaction beyond 12.0m depth. Although this analysis has shown relevance of the modified r_d factors, further need to confirm their general applicability as substitute to the widely used factors proposed by Seed et al can not be over stressed.

Based on this analysis, it was decided to densify soils to 80% relative density under the storage tanks to a depth of 10 m using compaction piling and vibrocompaction. The densification criteria was stated in terms of the observed SPT N=10 at surface and N=25 at 10 m depth with linear variation in between[3].

ANALYSIS AND DISCUSSION ON DENSIFICATION RESULTS

The effectiveness of the compaction piling process was established by installing piles in a test tank area at spacing varying from 5.0 D to 3.7 D in a triangular pattern, D being the pile internal diameter. These trials indicated a spacing of 4.3 D to compact the soil to the required level. The soil containing more than 20 percent fines was found not amenable to densification by compaction piling[4]. Also, the difference in Soil characteristics at sites other than the test tank area permitted the spacing satisfying the densification criteria to be increased from 5.0 D to 6.7 D[3] depending upon the existing soil conditions.

Based on machine characteristics, soil type, engineering judgement and experience, the soil was compacted to the desired level by vibroflotation with compaction points spaced at 2.0m intervals in a triangular pattern. However, with this spacing and pattern no improvement was observed in the soil layers containing more than 25 percent fines (reference 5, figs 8 & 9). The improvement made in the standard penetration values by the compaction piling process as well as vibrocompaction is compared in fig 3. It is seen that irrespective of the method of compaction employed, the improvement in the N values generally lay in the range of 1.5 to 3.0 times the original N values. Due to space limitations, observed settlement records of only a few tanks are presented in Table I. Low distortion values reveal that both the methods produced equally uniformly dense soil in the treated area and provided attention is paid to the limitation with regard to fines content, any of the two methods could be chosen for densification.

TABLE I : COMPARISON OF COMPACTION METHODS

Process	Observed Peripheral Settlement (mm)				Max. Ang. Distortion
	N	S	E	W	
Vibroflotation	26	23	32	27	1/4000
Compaction piles	29	27	33	28	1/3000
Compaction piles	25	27	29	24	1/5400

CONCLUSIONS

1. Depth reduction factors suggested by Nishiyama et al[2] predicted liquefaction depths of 10 to 11 metres consistent with the soil properties. Adoption of Seed's r_d factors[1] indicated unrealistically large liquefaction depths.

2. Compaction piles and vibroflotation are equally effective methods for densifying the Bongaigaon sand provided the fines content in the respective methods is limited to 20 and 25 percent.

REFERENCES

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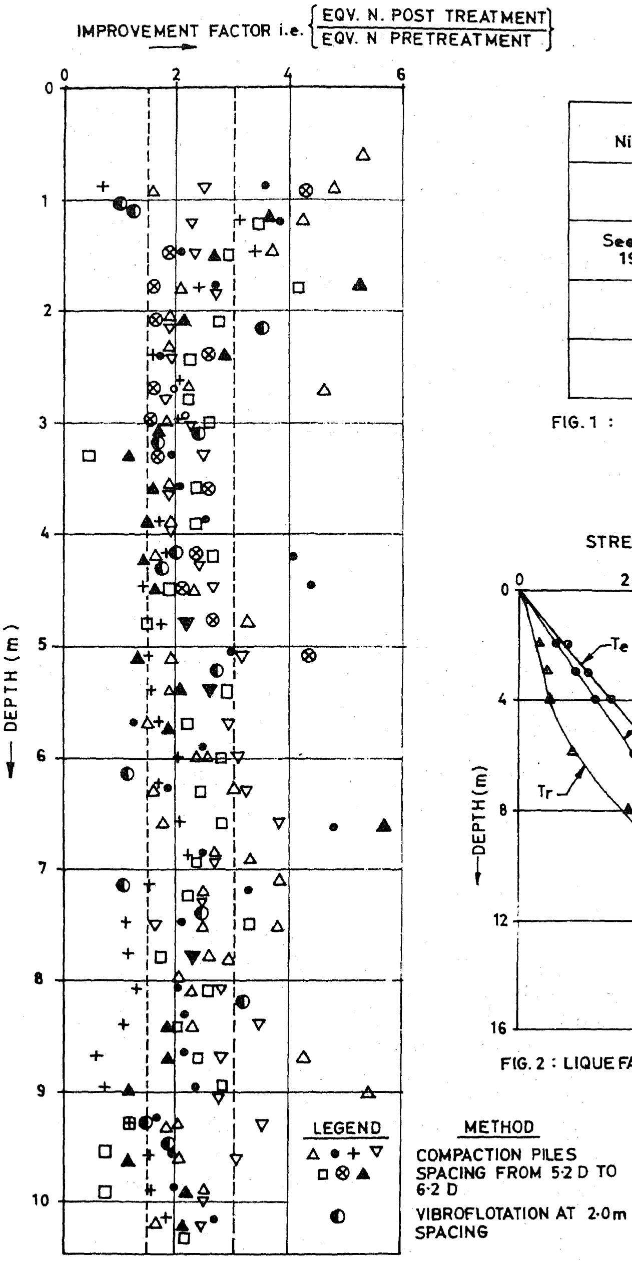

FIG. 3 : IMPROVEMENT CAUSED IN PENETRATION VALUES BY COMPACTION PILING AND VIBROFLOTATION

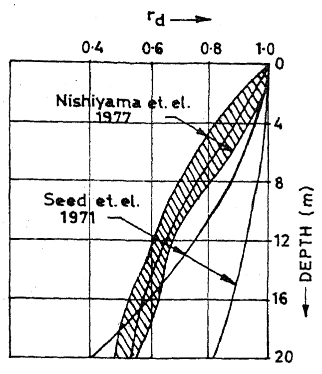

FIG. 1 : REDUCTION FACTOR r_d

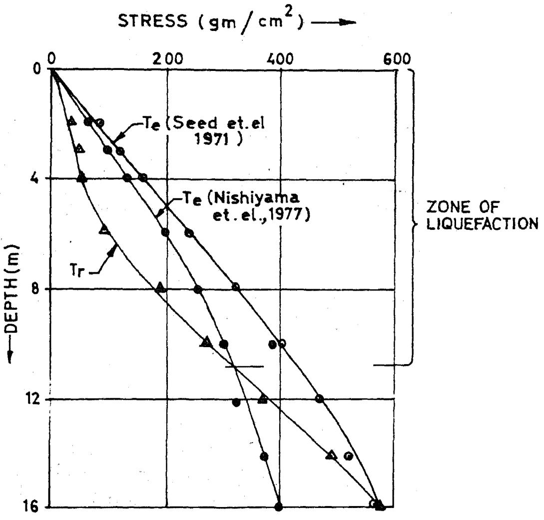

FIG. 2 : LIQUEFACTION POTENTIAL ANALYSIS