4ICEGE
Thessaloniki-GREECE 2007

4th International Conference on
Earthquake Geotechnical Engineering
June 25-28, 2007
Paper No. 1418

PRESENTATION OF A NEW GROUTING TECHNIQUE FOR LIQUEFACTION MITIGATION IN LITTORAL AREAS

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ABSTRACT

In most part of littoral areas such as the southern beach of Caspian Sea, soil liquefaction and related impacts is a major problem. Liquefaction potential of saturated soil can be decreased by various ground improvement methods including the grouting techniques. In this area uncased boring and conventional grouting technique is difficult because of high subsurface water level.
This paper presents the case study of a new grouting technique, by perforated micropile and grouting with integral packer, as a liquefaction countermeasure. In this method besides the low compaction effect of micropile driving in the adjacent soil, cement grouting with integral packer can also improve the geotechnical properties of the soil layers in any depth.
The experiment was performed in the construction project of residential complex on the Caspian Sea beach in Iran. According to the geotechnical investigations before the construction process, subsurface layers mostly consist of very loose silty sand with a high potential of liquefaction, up to 14 m below the ground surface. As a solution, perforated micropiles were driven in a 3m × 2.7m pattern and cement grouting by the system of integral packer was implemented. Evaluation of Standard Penetration Test (SPT) results, before and after the improvement process, implies that this method can effectively improve the strength of loose, liquefaction susceptible soils in littoral areas like the southern beach of Caspian Sea.

Keywords: Cement grouting; integral packer; liquefaction mitigation; littoral area.

INTRODUCTION

In the presence of strong ground motion, liquefaction hazards are likely to occur in saturated cohesionless soils. Liquefaction primarily occurs in geologically young sediments of sands and silts in areas with high ground water levels. On the construction site of a 110 unit residential complex at southern beach of Caspian Sea, geotechnical investigations showed the high liquefaction potential of subsurface soil layers.

Many ground improvement techniques such as densification methods, mixing methods, drainage, dewatering and grouting methods can reduce or eliminate liquefaction potential. Through these methods, grouting is most efficient in residential zones and near existing structure. The grouting process can improve the soil features by strengthening the touching surface of grains and making a stronger and stiffer skeleton than that of the primary soil.

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In this project, for liquefaction mitigation and soil improvement, grouting technique was proposed. In littoral area like this, uncased boring and conventional grouting technique is difficult because of high subsurface water level, so in order to improve the mechanical properties of soil layers, perforated micropiles incorporated by integral packer grouting was utilized.

This method has more advantage than other grouting method such as simple compaction grouting and grouting via tube-a-manchette, especially in soft to medium density soil because of its low cost and common labour and facilities requirement. For example the total cost of this method was about 40% of the cost of grouting via tube-a-manchette witch was used for grouting in similar project.

In this method besides the compaction effect of micropile driving in the surrounding soil, cement grouting can also improve the geotechnical properties of the soil layers. Perforated micropiles create a casing that grouting by integral packer can be performed well. Also this method was very safe, fast, versatile and economic versus other mitigation methods.

SUBSURFACE CONDITION

This project is located on the southern beach of Caspian Sea and covers an area of 3000 m^2 . Six story steel structures are founded on mat foundation. According to site investigation the soil of this site from surface to the depth of about 20 meters is composed of silty sand layers. Also some lenses of clay and clayey sand with limited thickness were observed. Sandy layers located in depth less than 15 m were not compacted and categorized as soft to very soft soils. In depths more than 15 m, the density of soil is more and the soil layers are in the category of dense to very dense soils. The most portions of the layers were silty sand soil and the ground water table is in depth 1 to 2 m from surface. An interpreted subsurface section, based on all of the collected subsurface data, is shown in Fig.1.

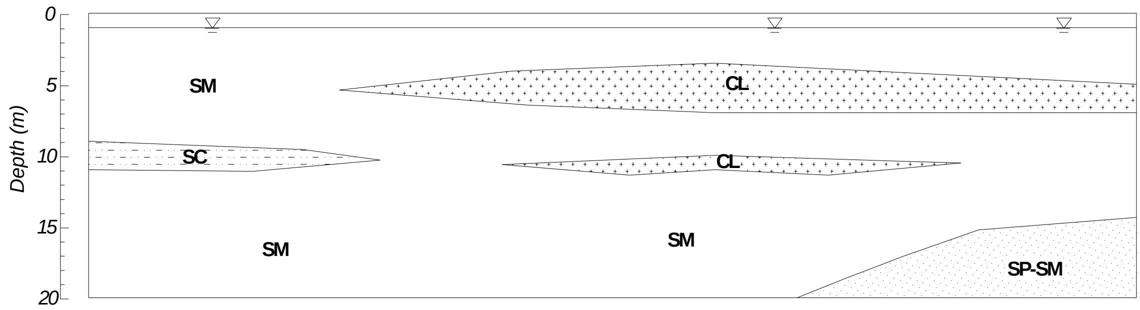

Figure 1. Generalized soil profile through project area

In order to characterize the soil layers of the project site three boreholes (BH-1b, BH-2b, and BH-3b) with 20 m depth were drilled. During this process, Standard Penetration Tests were done in different layers. In table 1 the data of one borehole is presented. Evaluation of SPTs results was known that in this area subsurface soil layers were susceptible to liquefaction.

PERFORATED MICROPILE AND INTEGRAL PACKER GROUTING

Perforated Micropile and grouting by Integral Packer is Nofan's proprietary technology and is patented under no. wo 03/044282 in World Intellectual Property Organization (WIPO). Perforated micropile consists of steel pipes with external radius of 76 mm and internal radius of 68 mm, perforated by 6 mm holes, 80 no’s per meter length. Micropiles are driven or installed after drilling boreholes into the ground to sufficient depth. Then Grouting is performed by integral packer in frequent stages from bottom to top. Grout consists of cement and water and different additives if needed. Grout is injected under pressure between 5 to 15 bars depending on ground type or depth.

Table 1. SPT bow counts prior to grouting

Depth	Density KN/m^3	BH-1b		
		Fine %	N	$(N1)_{60}$
1 m	18.7	15	5	*6.38*
2 m	18.8	15	5	*6.38*
3 m	18.8	15	4	*6.26*
4 m	18.9	15	4	*5.09*
5 m	18.9	15	3	*4.16*
6 m	19	27	4	*5.05*
7 m	18	100	4	*4.69*
8 m	18	100	3	*3.31*
9 m	18	15	4	*4.4*
10 m	19.3	5	13	*13.55*
11 m	19.3	5	15	*17.33*
12 m	19.2	7	22	*20.81*
13 m	19.4	17	1	*0.91*

Fig.2 presents the schematic form of NOFAN's micropiles. The construction of micropile involves a succession of processes, the significant of which are drilling, packer installation and grouting. This method requires simple equipment and facilities. For micropiles driven into the ground, a primary pile hammer is used. The photo of this apparatus is presented in Fig.3.

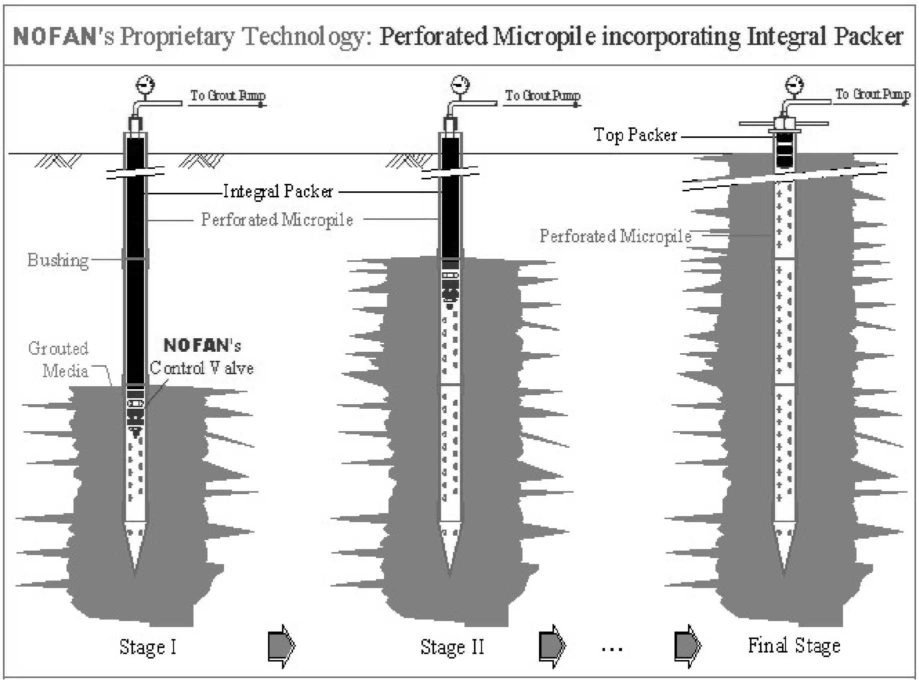

Figure 2. Schematic form of NOFAN's perforated micropile

In this project the overall design is consist of 350 micropiles with depth of 4, 8 and 14 m and the total length of 3112 meters. The micropiles were driven in a pattern of 3.0 m by 2.7 m. The cement grout was injected with a minimum pressure of 10 bars and maximum pressure of 15 bars. The ratio of water to cement is varied from 0.5 to 1.0, dependent on the situation. In the primary design the cement take was considered equal to 250 kg per meter length of micropile, but according to the ground conditions this amount was increased up to average of 320 kg per one meter length. The process of integral packer installation is conducted in every 2 m.

Figure 3. Photo of micropile driven hammer

EVALUATION OF GROUND IMPROVEMENT

After micropiles installation and grouting into perforated micropiles by integral packer system, in order to evaluate the improvement of ground conditions additional SPT testing were conducted in four boreholes with maximum 15 m depth (BH-1a, BH-2a, BH-3a, and BH-4a). Fig.4 showed the location of micropiles and additional SPT boreholes.

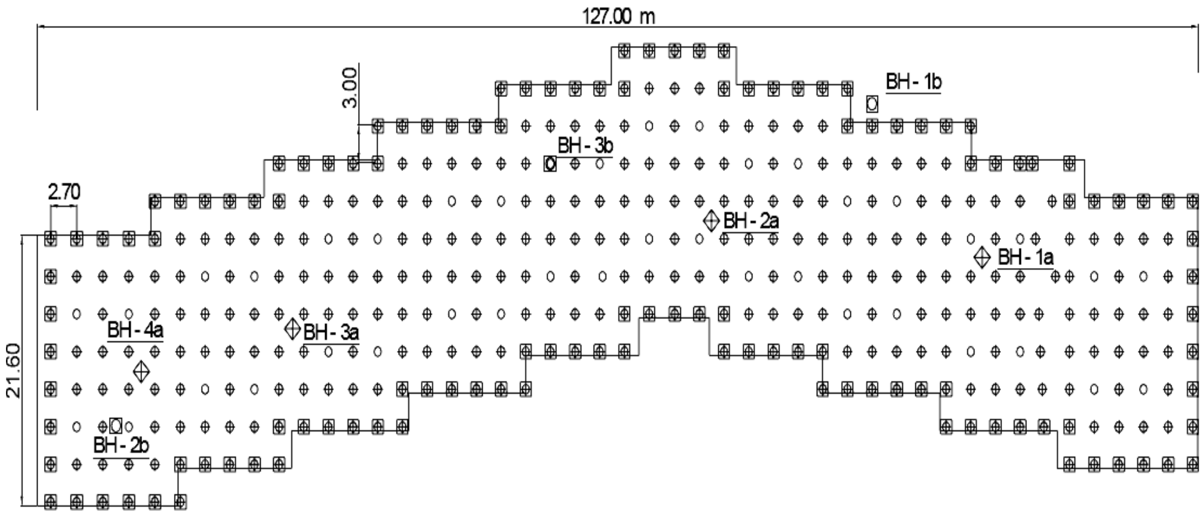

Figure 4. Plan of Micropils pattern and SPT boreholes location

All of the raw field data was carefully investigated and nonrepresentative SPT blow counts, those in grout layers or blow counts in soil layer transitions were discarded. The data was also normalized per Seed et al (1985) i.e., adjusted for depth of sample or its confining pressure. The SPT data was sufficient to evaluate the overall ground improvement. The normalized SPT blow counts before and after grouting were evaluated and the liquefaction potential analyzed following the procedures of Seed and De Alba (1986) and Seed and Idriss (1982). These data are presented in Table 1 and 2, and show the ground improvement for the 3.0 m micropile spacing. For the Sandy Silts, the SPT blow count (arithmetic average) increased from 7 before grouting to 30 after grouting.

In liquefaction analysis, the factor of safety against liquefaction was calculated for individual SPT blow counts at specific depth. The seismic criteria, magnitude 7.5 and peak horizontal ground acceleration of 0.35g were previously established for the site. A plot of the calculated safety factors from data before and after grouting is in Fig.5. These data and the result of another bore holes in this site, clearly show significant improvement throughout. The average of safety factor generally increased from 0.35 before grouting, to 4.16 after micropile installation and grouting process.

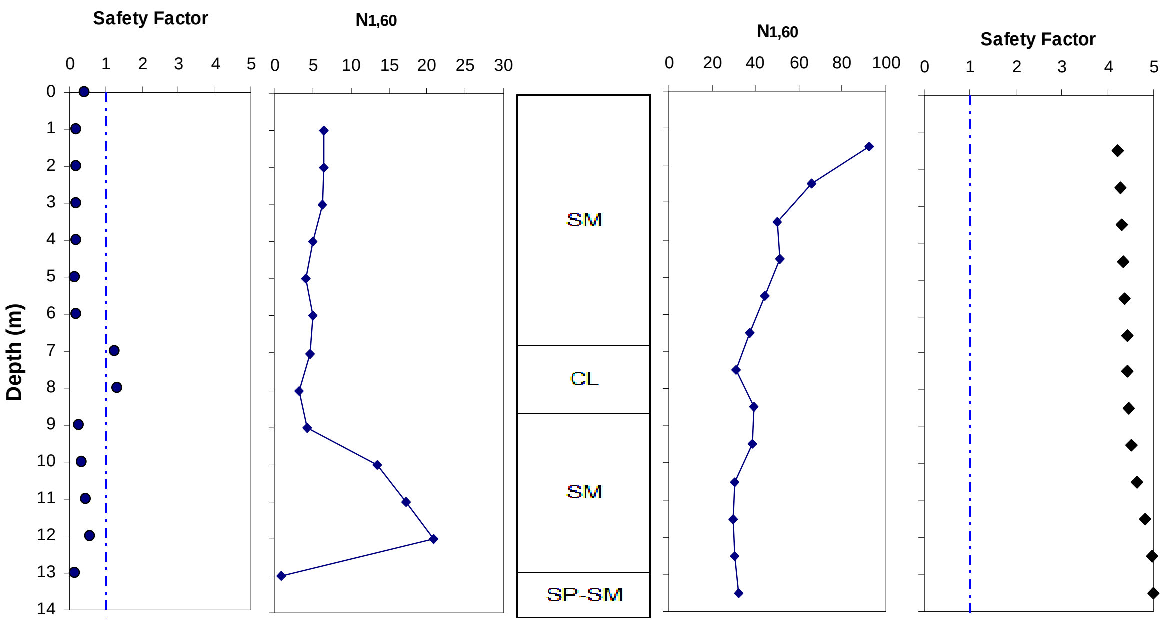

Figure 2. Typical SPT data analysis before (left) and after grouting (right)

CONCLUSIONS

In this paper an experience for mitigation of soil liquefaction, in a project on the Caspian Sea beach was explained and perforated micropile incorporated integral packer, as a new technique for grouting in the littoral area was presented. Perforated micropiles with integral packer system, is a combination of micropile and grouting. In this method besides the compaction effect of micropile driving in the surrounding soil, cement grouting can also improve the geotechnical properties of the soil layers. In the littoral areas because of high water level, uncased boring and conventional grouting technique is difficult, so in order to improve the soil layers, this technique was utilized.

To evaluate the effect of perforated micropile and grouting by integral packer on liquefaction potential, SPT tests were performed before and after the grouting. SPT results were shown that this technique effectively was improved the strength of soil layer and typically the average of safety factor against liquefaction increased from 0.35 before improving to 4.16 after micropile installation and grouting by integral packer.

Perforated micropiles incorporated by integral packer grouting could be used to mitigate liquefaction of the susceptible soils and create a buttress zone to protect the facility and buildings. Perforated micropiles create a casing that grouting by integral packer can be performed easily in littoral area. The experience of using micropiles with integral packer system in this project and other similar projects (such as 40 and 44 unit residential complex) verify the performance of this method in decreasing the liquefaction potential of the soil types like that of the Caspian Sea beach. Also this method is very safe, fast, versatile and economic versus other mitigation methods. This method has more advantage than other grouting method such as simple compaction grouting and grouting via tube-a-manchette, especially in soft to medium density soil because of its low cost and ordinary labor and facilities requirement.

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