Improving liquefaction potential strength by using micropiles

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Abstract: During cyclic loadings, such as those produced by earthquakes, liquefaction of undrained saturated cohesionless materials are well recognized as being the main devastating phenomenon on structures. Various remedial treatment methods for this type of soil are widely used, such as densification methods by compacting the soil, solidification methods by increasing the density of the material, or lowering the water table down to improve the effective stress of the in situ soil. Remedial treatment methods of soils to avoid possible initiation of liquefaction are based either on the principle of improving the characteristics of the soil or by means of draining the water, and thus present the same disadvantages modifying the in situ soil before construction. This research will study an alternative system using micropiles. This reinforces the soil by its structural elements rather than changing its properties. Micropiles have been used effectively in many applications of ground improvement to increase the bearing capacity and reduce the settlement particularly in strengthening existing foundations.

This paper deals with a case study in which micropiles have been used to improve the liquefaction strength of the soil by using the results of Standard Penetration Test (SPT) on a real site, before and after installation of the micropile systems. The results show that, using micropiles reduces the liquefaction potential of the soil.

Résumé: Pendant les chargements cycliques, tels que ces produit par les tremblements de terre, la liquéfaction de matériels de cohesionless undrained saturés sont bien a reconnu comme est le phénomène qui dévaste principal sur les structures. Les diverses méthodes de traitement réparatrices pour ce type de sol sont largement utilisées, tel que les méthodes de densification par comprime le sol, les méthodes de solidification en augmentant la densité du matériel, ou abaisser la table d'eau en bas pour améliorer la tension efficace du dans le sol de situ. Les méthodes réparatrices de traitement de sols pour éviter l'initiation possible de liquéfaction est basée ou sur le principe d'améliorer les caractéristiques du sol ou au moyen de drainer l'eau, et ainsi les désavantages pareils présents modifiant le dans le sol de situ avant la construction. Cette recherche étudiera un micropiles d'utilisation de système alternatif. Ceci renforce le sol par ses éléments au lieu de changer structuraux ses propriétés. Micropiles a été efficacement utilisé dans beaucoup d'applications d'amélioration de sol pour augmenter la capacité de maintien et réduit le règlement particulièrement dans fortifier les fondations existantes. Ce papier traite une étude de cas dans lequel micropiles a été utilisé pour améliorer la force de liquéfaction du sol en utilisant les résultats de Test de Pénétration Standard (SPT) sur un vrai site, avant et après l'installation des systèmes de micropile. Les résultats montrent cela, utilisant micropiles réduit le potentiel de liquéfaction du sol.

Keywords: cohesionless materials, liquefaction, strength, standard penetration test, micropiles

INTRODUCTION

In the presence of strong ground motion, liquefaction hazards are likely to occur in saturated cohesionless soils. Soil liquefaction improvement options can be characterized as densification, drainage, reinforcement, mixing or replacement. Densification methods, modifications leading to improving the cohesive properties of the soil (hardening or mixing), removal and replacement, or permanent dewatering can reduce or eliminate liquefaction potential. Other methods such as reinforcement of the soil or the use of shallow or deep foundations designed to accommodate the occurrence of liquefaction and associated vertical and horizontal deformations may also achieve mitigate risk to an an acceptable level. The choice of mitigation method will depend on the likely extent of liquefaction and the related consequences. Also, the cost of mitigation must be considered in light of an acceptable level of risk. Youd (1995) has suggested that structural mitigation for liquefaction hazards may be acceptable where small lateral displacements and vertical settlement are predicted.

The most widely used techniques for in – situ densification of liquefiable soils are vibro- compaction, vibro-replacement, deep dynamic compaction, and compaction (pressure) grouting (Hayden and Baez 1994). Hardening and /or mixing techniques seek to reduce the void space in the liquefiable soil by introducing grout materials either through permeation, mixing mechanically, or jetting. These techniques are known as permeation grouting, soil mixing, or jet grouting. Design methodology and implementation of these techniques are described by Baker (1992) and Moseley (1993).

Remedial treatment methods of soils to avoid possible initiation of liquefaction are based either on the principle of improving the characteristics of the soil or by means of draining the water, these activities being performed before construction. This research presents an alternative system using micropiles, and raises the benefits of strengthening the soil by reinforcing it with structural elements.

Micropiles have been used effectively in many ground improvement applications to increase the bearing capacity and reduce settlement, particularly in strengthening existing foundations. Design methodology and implementation of these techniques are described in FHWA-SA-97-070.

This paper deals with a case study in which micropiles have been used to improve the liquefaction strength of loose sandy soil using the results obtained from the Standard Penetration Test (SPT) taken at the site before and after installation of the micropile systems.

SITE INVESTIGATION

The region under study is located in the low lying strip of coastal land next to Persian Gulf in Bandar Abbas (Southern Part of Iran). The project site is related to building of Bandar Abbas post office. To identify the on-site soil stratigraphy, three boreholes were drilled to depths of 15 m at pre-determined locations using a rotary drilling rig. During the drilling operations, Standard Penetration Tests were performed. Undisturbed and disturbed sampling was also performed at various depths. To classify the subsurface soils and determine their physical, chemical and mechanical characteristics laboratory tests were performed on the samples obtained during the drilling process.

Soil stratification

Based on the results of laboratory and in-situ tests, the soil layers between ground surface and bottom of borehole are formed of varying clean and silty sands (SM, SP). Intermittent layers of sandy clay (CL) and sandy silt (ML) with limited thickness were recognised. Ground water level was found to be at depths of 1m from the ground surface during drilling. Based on the SPT results, soil layers at depths less than 8 m are classified as loose sandy soils. With increasing depth the compaction of the soil layers increased. Due to the high ground water level and loose sandy soil layers on site which would be prone to liquefaction, evaluation of liquefaction potential was considered to be imperative.

Liquefaction potential evaluation procedure

To determine the liquefaction potential the directive issued by the National Center for Earthquake Engineering Research (NCEER-1997) was followed. In this directive, evaluation methods of liquefaction potential for sandy and clayey soils are considered and relevant procedures with respect to soil type are applied to determine liquefaction potential of the soil.

In NCEER-97directive Professor Seeds recommendations are used to assess the liquefaction potential in sandy soils. Two quantities have to be determined: 1) Cyclic Stress Ratio (CSR) and 2) Cyclic Resistance Ratio (CRR).

Cyclic stress Ratio

Using Seed and Idriss (1981), CSR is determined using the following equation:

$$CSR= (\tau_{av} / \sigma'_{v0}) =0.65\ (a_{max}/g)\ (\sigma_{v0}/\sigma'_{v0})\ r_d$$

where: τ_{av} is the average shear strength in kPa, σ'_{v0} is the effective over burden pressure at depth considered in soil layer in kPa, a_{max} is the maximum horizontal acceleration caused by an earthquake at ground surface in m/s^2,g is the ground acceleration in m/s^2, σ_{V0} is the total overburden pressure at depth considered in soil layer in kPa and r_d is the shear stress reduction coefficient with depth. NCEER-97 has recommended the following relations to determine shear stress reduction coefficient with depth (r_d):

$$r_d=1.0-0.00765Z \qquad Z \le 9.15(m)$$

$$r_d=1.174-0.0267Z \qquad 9.15 < Z \le 23(m)$$

The maximum horizontal ground acceleration is taken as: a_{max} =0.35 g.

Cyclic Resistance Ratio (CRR)

The most reasonable method to determine CRR is to obtain undisturbed soil samples and perform cyclic shear tests. Due to difficulties in obtaining satisfactory undisturbed samples from granular soils, use of in-situ tests for liquefaction studies are now encouraged.

At present, many in-situ tests are available to determine liquefaction potential, for instance Cone Penetration Test (CPT), Standard Penetration Test (SPT) and measurement of shear wave velocity (v_s).

Determination of CRR based on SPT results was first proposed by Seed and presented as a diagram in 1985. In 1997, this diagram was reviewed by NCEER and eventually Figure 1 was prepared. Here, based on data collected from sites of past earthquakes with / without liquefaction, a base curve for clean sand is given. Using a corrected SPT value $(N_1)_{60}$, CRR is determined from the given curves. In silty sands the effect of fines content must be accounted for. To do this, the equivalent corrected SPT value is defined as follows:

$$(N_1)_{60cs}=K_S\ (N_1)_{60}$$

where K_S is the fines content correction factor and is calculated as:

$K_s = 1 + [(0.75/30)(FC-5)]$

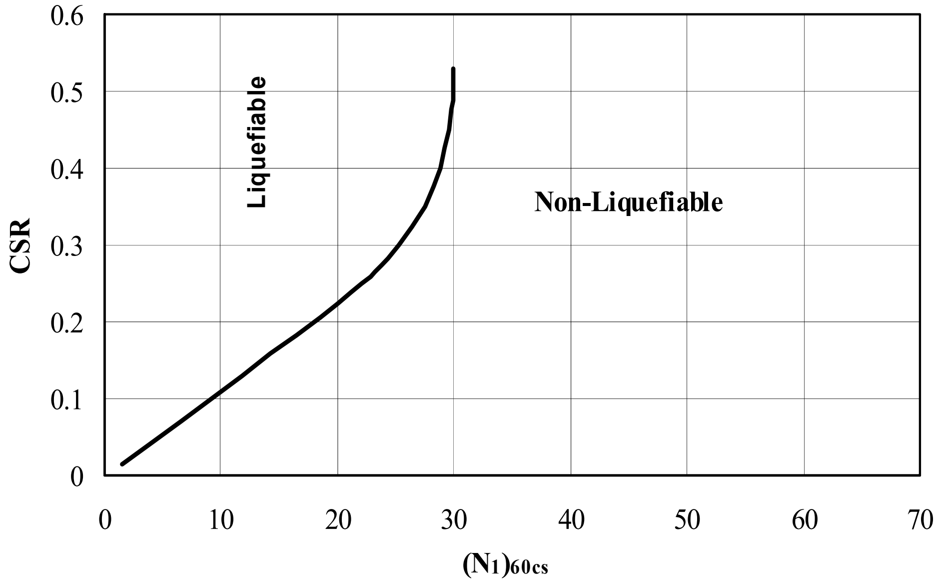

Figure 1. Evaluation of liquefaction potential (NCEER-97) of sandy soils

The factor of safety against liquefaction will be determined with following equation:

F.S=CRR/CSR

Liquefaction Potential Evaluation in this project

For all 3 boreholes liquefaction potential are determined. For this purpose, the corrected SPT values are evaluated at various depths based on NCEER-97 procedure. Then the liquefaction potential is determined. The results are presented in Tables 1 and Figures 2-4. It can be concluded that, at depths less than 5.0 m (due to existence of loose saturated sandy layers), liquefaction is likely to occur and the safety factor is less than 1.

Table 1. Liquefaction potential evaluation in Boreholes (before & after Micropile Installation)

Boreholes	Z (m)	USCS	σ_{v0} (kPa)	σ'_{v0} (kPa)	CSR	Before Micropile Installation			After Micropile Installation		
						$(N_1)_{60CS}$	CRR	F.S	$(N_1)_{60CS}$	CRR	F.S
BH#1	1	SM	20.0	10.0	0.452	35	0.567	1.254	38	0.846	1.872
	2	SM	40.0	20.0	0.449	30	0.459	1.022	35	0.638	1.420
	3	SP-SM	60.0	30.0	0.446	24	0.267	0.600	34	0.509	1.143
	4	SP-SM	80.0	40.0	0.443	22	0.240	0.543	36	0.638	1.442
	5	SP-SM	100.0	50.0	0.439	19	0.205	0.467	35	0.567	1.292
BH#2	1	SP-SM	20.0	10.0	0.452	28	0.343	0.759	36	0.638	1.411
	2	SP-SM	40.0	20.0	0.449	28	0.343	0.764	37	0.728	1.621
	3	SM	60.0	30.0	0.446	63	N.L.		73	N.L.	
	4	SM	80.0	40.0	0.443	54	N.L.		65	N.L.	
	5	SP-SM	100.0	50.0	0.439	22	0.240	0.467	35	0.567	1.292
BH#3	1	SM	20.0	10.0	0.452	29	0.375	0.829	35	0.567	1.254
	2	SM	40.0	20.0	0.449	32	0.450	1.002	35	0.567	1.263
	3	SM	60.0	30.0	0.446	55	N.L.		60	N.L.	
	4	SM	80.0	40.0	0.443	32	0.450	1.017	36	0.638	1.440
	5	SM	100.0	50.0	0.439	31	0.450	1.024	37	0.728	1.658

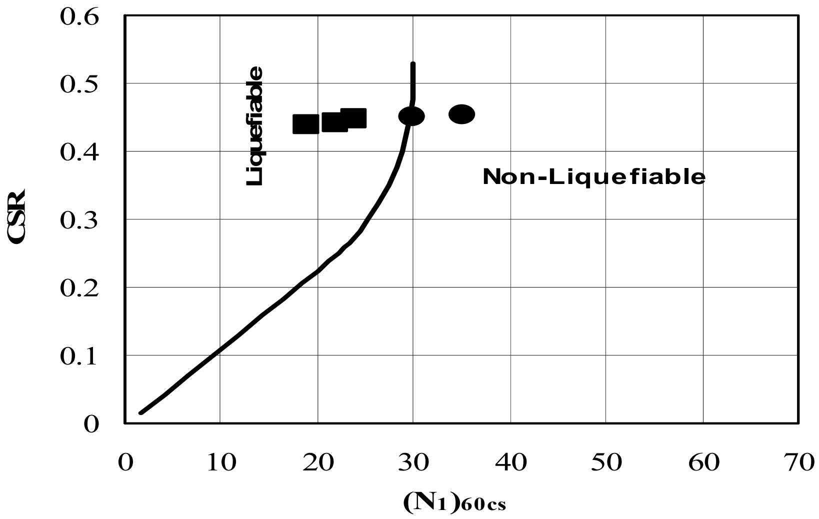

Figure 2. Liquefaction potential evaluation in BH#1 (Before micropile installation)

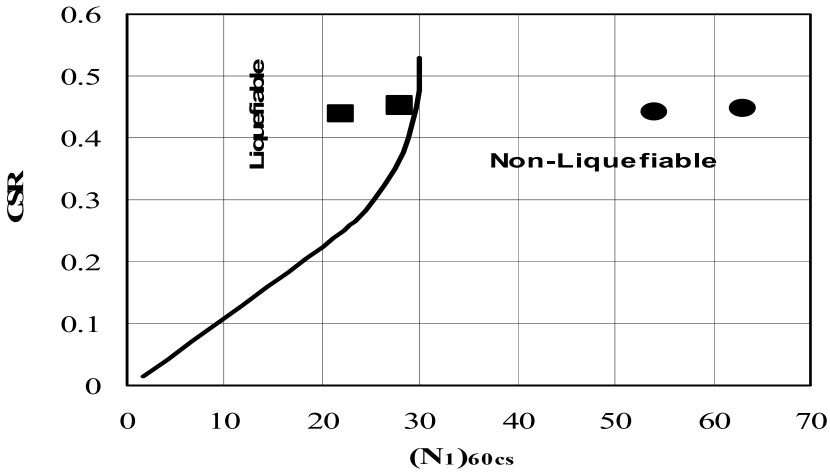

Figure 3. Liquefaction potential evaluation in BH#2 (Before micropile installation)

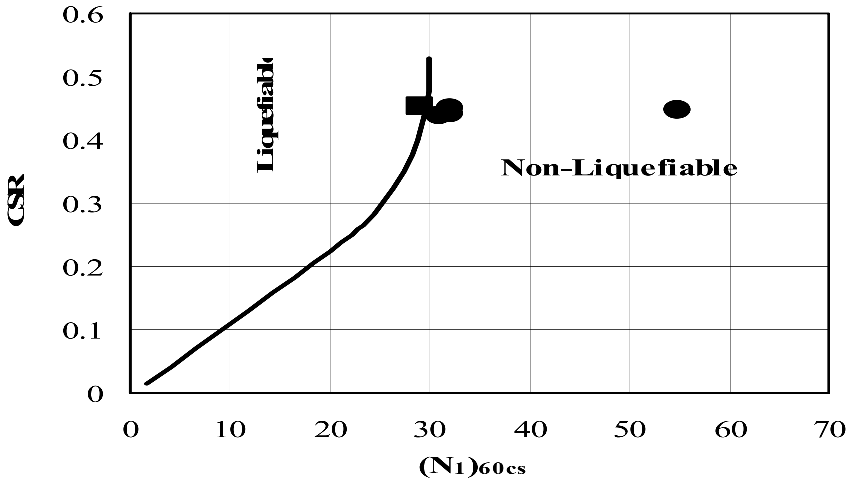

Figure 4. Liquefaction potential evaluation in BH#3 (Before micropile installation)

IMPROVING LIQUEFACTION POTENTIAL USING MICROPILES

Considering the weakness of the soil on the site, use of micropiles to improve soil properties is technically and economically a suitable method among various alternatives available. Here, by installing micropiles together with grouting under pressure and use of proper admixtures, the mechanical and geotechnical properties of soil are considerably improved. The reinforced soil mass created acts as a resistant coherent body improving the compaction properties of loose layers and also providing suitable load bearing capacity to transfer structural loads to the ground.

The micropiles used consisted own of porous steel tubes with 75 mm outer and 68 mm inner diameters. Two types of micropiles with lengths of 8 and 12 m were used. The grouting pressure for each micropile was about 10 to 12 atmosphere. Standard Penetration Tests were performed after micropile installation. Then, the liquefaction potential of soil layers was calculated after soil improvement based on the new SPT results. The results obtained are shown in Table 1 and Figure 5-7. It is shown that the SPT values of soil layers are increased after soil improvement with micropile installation. Therefore the liquefaction resistances of sandy soil are modified.

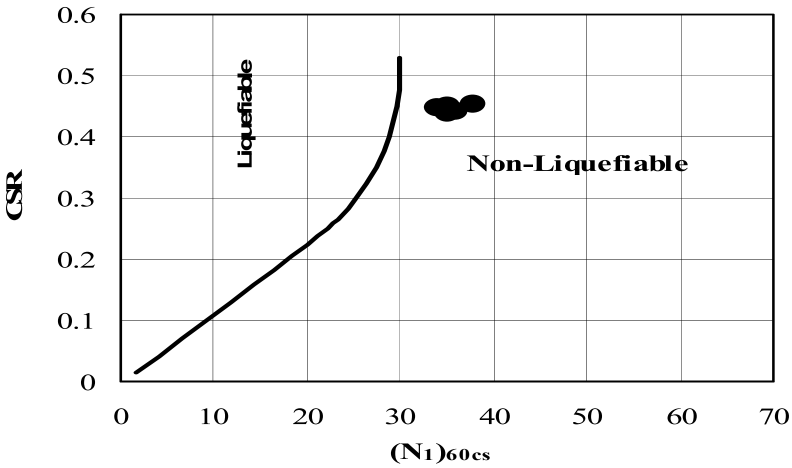

Figure 5. Liquefaction potential evaluation in BH#1 (After micropile installation)

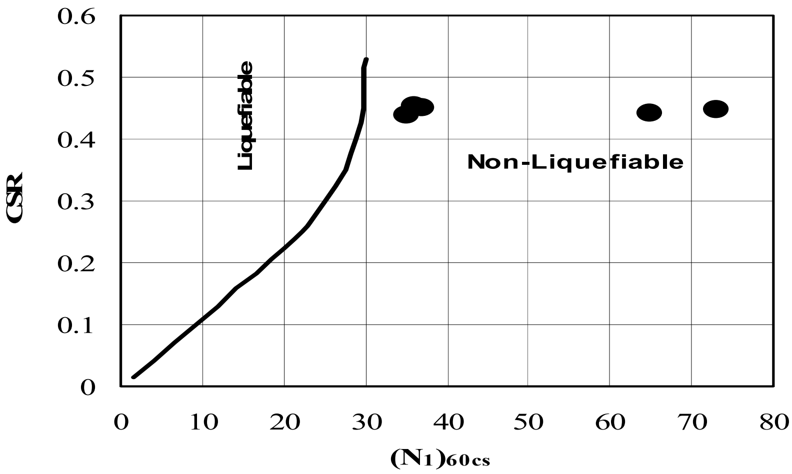

Figure 6. Liquefaction potential evaluation in BH#2 (After micropile installation)

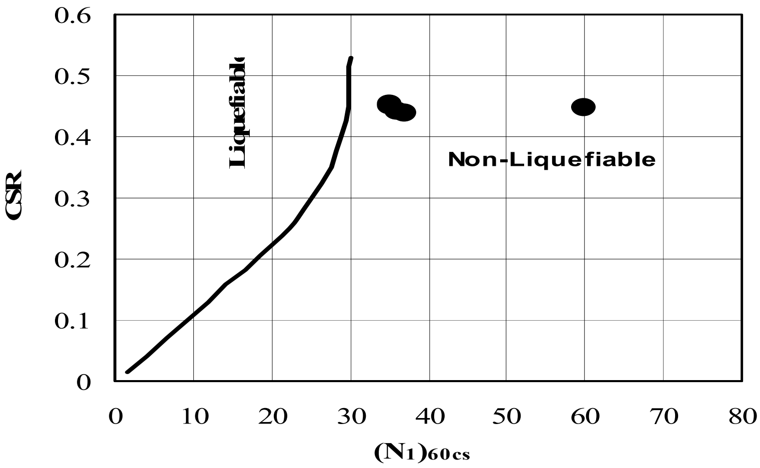

Figure 7. Liquefaction potential evaluation in BH#3 (After micropile installation)

CONCLUSIONS

A case study in which micropiles have been used to improve the liquefaction strength of loose sandy soil by using the results of the Standard Penetration Test (SPT) on a real site, before and after installation of the micropile system is presented here. Based on the SPT results, the following conclusions may be drawn**:**

1) Micropile installation techniques is a practical and useful method for improvement of liquefiable soils.

2) At the site, liquefaction is likely to occur at depths less than 5.0 m due to existence of loose saturated sandy layers, and the safety factor is less than 1.

3) The SPT values of soil layers are increased after soil improvement with micropile installation. Therefore the liquefaction resistances of sandy soil are modified.

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