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Land Reclamation Project in Anzali Harbor Using Dynamic Compaction

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Keywords

Land reclamation,
Dynamic compaction,
Standard penetration test,
Cone penetration test.

Abstract

Dynamic compaction used as a soil improvement method for treatment of reclaimed lands in Anzali, Iran. Land reclamation was performed by filling dredged soil and dynamic compaction was employed for mitigation of liquefaction potential and excessive settlements during operation. The compaction pattern and phases, energy and rest periods were designed based on the fill materials characteristics. Engineering geological studies in this project were divided into two phases. In first phase, study of the sea floor and available filling materials was performed before reclamation. In second phase, study of suitability of the reclaimed land for construction purposes before and after improvement was carried out. In situ tests showed that reclaimed land is susceptible to liquefaction hazard and settlement potential. Dynamic compaction was selected for improvement of reclaimed land. Final compaction pattern was revised according to the results of the trial compaction efforts. Corrected standard penetration test numbers and one penetration test values after the dynamic compaction showed more than 20 and 7 MPa increase respectively. In-situ tests results proved that the liquefaction potential hazard has been abated due to the dynamic compaction and bearing capacity of the reclaimed land has improved.

1. Introduction

Anzali Especial Economic Zone is located in Anzali harbor, the north of Iran. Economic growth and growing necessity of new business sites and the lack of the sufficient vacant areas has urged land reclamation by dredging soil up to depth 10m in an area about 35 Hectare.

Land reclamation through hydraulic filling of dredged materials results in loose deposits which cannot be improved by surface tamping and compaction. This means that more efficient and in-depth improvement techniques are required to modify the state of compaction of the loosely packing sand particles. Several methods of deep compaction are available for the densification of granular soils; among these, dynamic compaction is one of the effective methods for densifying granular soil in situ to a great depth. However, the success of dynamic compaction is affected by many factors, several of which are not yet fully understood. Dynamic compaction has become a popular method worldwide for deep improvement of loose soils in last decades. Dynamic compaction pioneered by Menard and Broise [1] has been used for improvement of deep soil layers for decades. In this method, through falling a tamper of 5t-30t from 10m-30m height, improvement depths of 3−9 m are obtained [2]. Soil improvement has been investigated by assessing the experimental tests like standard penetration test (SPT), cone penetration test (CPT) and pressure meter test (PMT) before and after compaction [3-7]. Regarding to the high earthquake hazard in region and heavy loading due to petrochemical installations, improvement of weak filled material for mitigation of liquefaction potential and settlement of footings is normally carried out. Dynamic compaction technique was selected for treatment of filling material based on material type and geological conditions. Existence of some faults around site and earthquake history of region alarms that the earthquake hazard is serious and imminent. Based on the earthquake hazard analysis, design earthquake magnitude is 7.5 in Richter scale and peak ground acceleration is expected to be 0.3g.

This paper describes the dynamic compaction method used at the Anzali harbor reclamation site (Figure 1) for the improvement of reclaimed sandy fill. Field data collected were used to investigate the effectiveness of the densification method and the effect of various factors, critical to the success of dynamic compaction treatment was investigated. This paper describes the characteristic of geological site, geotechnical aspects of materials and dynamic compaction project in Anzali. Moreover, the performance and efficiency

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of dynamic compaction for treatment of filled material is discussed.

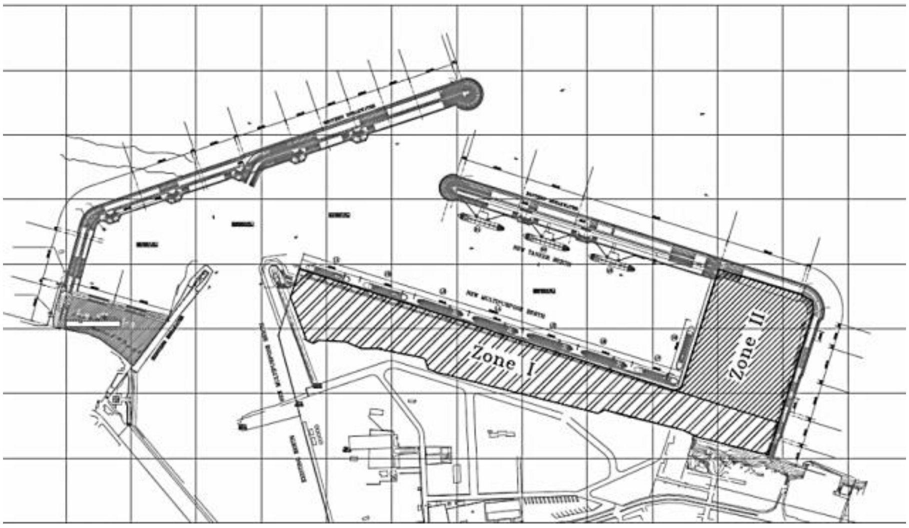


Figure 1. Location of Anzali harbor reclamation project

2. Liquefaction Potential and Settlement Criteria

With considering filling method, deploying alluvial materials in sea water, filling materials were accumulated in loose conditions in and above sea water. Also grading of filling materials contained fine grain materials like silt particles. This condition would result in low bearing capacity and excessive settlement in static loading condition and liquefaction potential in dynamic loading due to earthquakes. The engineering geological studies are necessary to determine applicability of reclaimed land for construction of structures. To evaluate the liquefaction potential, SPT test s were conducted at different depths of boreholes drilled in reclaimed land. The simplified procedure proposed in two workshops [8] was used to determine factor of safety against liquefaction potential. In this procedure, the cyclic stress ratio (CSR) from earthquakes is computed from Eq. (1) proposed by Seed and Idriss [9]. Cyclic resistance ratio (CRR) which is calculated from (N1)60 will then be compared with the CSR according to Figure 2.

$$\mathrm{CSR} = (\frac{\tau_{avg}}{\sigma_0} = 0.65\left(\frac{a_{max}}{g}\right)\left(\frac{\sigma_v}{\sigma_v'}\right).r_d \qquad (1)$$

where

τ_{avg}: Average shear stress

σ_0: Total overburden pressure

a_{max}: Maximum acceleration from earthquake on ground surface

σ_v: Total vertical stress

σ_v': Effective vertical stress

r_d : Stress reduction ratio related to depth can be computed from Eqs. (2) and (3) proposed by Liao and Whitman [10]

$$r_d = 1 - 0.00765z \qquad For \quad z \leq 9.15 \qquad (2)$$

$$r_d = 1.174 - 0.0267z \qquad For \quad 9.15 < z < 23 \qquad (3)$$

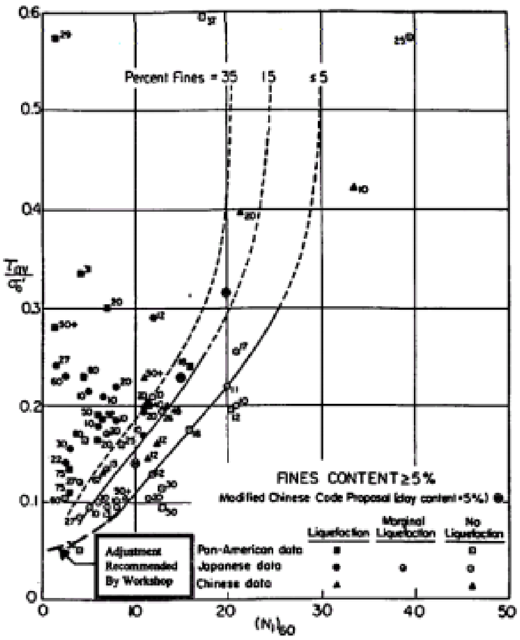


Figure 2. Curves of liquefaction potential control

For settlement control, mat bearing capacity equivalent to 25mm allowable settlement is estimated according to Eq. (4) [11]

$$q_a = 0.84C_b(N_1 - 3)\omega_\gamma \qquad (4)$$

where

q_a: Allowable bearing capacity for 25mm allowable settlement

C_b: Correction factor ($C_b = 1$ for silty sand)

N_1: SPT value

ω_γ: Decrement factor

Figure 3 shows position of boreholes used in the dynamic compaction works at Anzali harbor. According to the liquefaction potential and settlement criteria, Figure 4 was reached where the required depth of improvement is equal to the depth of the embankment.

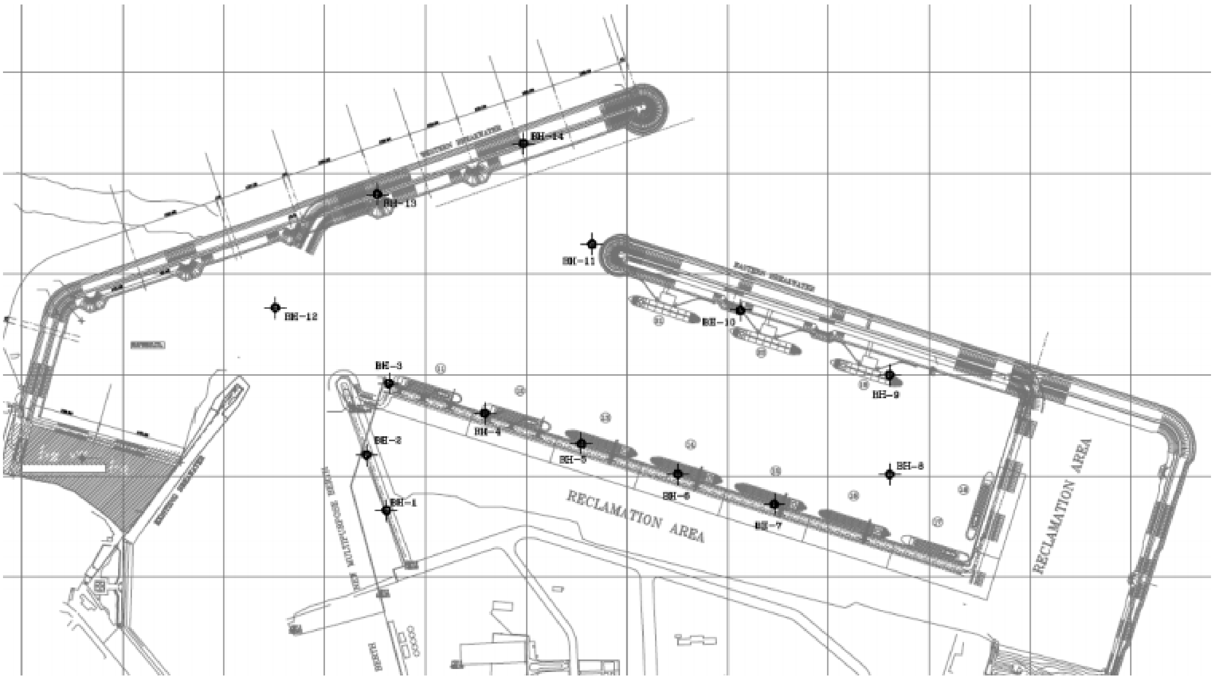


Figure 3. Location of boreholes used in the dynamic compaction procedure

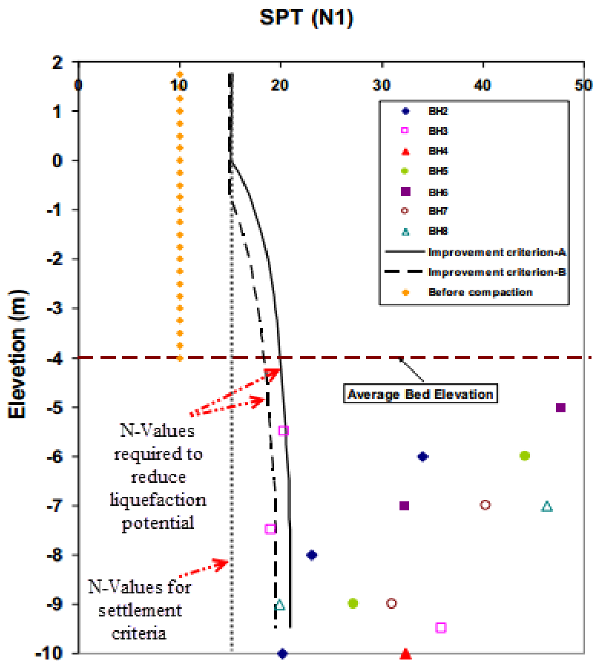


Figure 4. Depth of improvement required for liquefaction potential and settlement criteria

3. Dynamic Compaction Performance

Dynamic Compaction technique is efficiently applicable to a wide range of soils, from silty sands and collapsible soils to large diameter boulders [12, 13]. Research also suggests that this technology is relatively environmentally friendly and produces less carbon emissions than alternative technologies [14].

In Anzali harbor reclamation project, various combinations of weight and drop height were evaluated. Desired area for treatment was divided to four zones as I-A, II-A, I-B and II-B according to filling material depth. In each zone some trial areas (TC1-I, TC2-I and TC3-I) were selected to perform dynamic compaction to get optimum pattern (Figures 5 and 6). Different patterns were selected and used for trial areas as showed in Table 1.

Usually, the thickness of the loose deposit and hence the required depth of improvement is known from subsurface exploration. The relationship between the depth of improvement and tamper mass and drop height is as follows [15] (Eq. (5))

$$D = n\sqrt{W.H} \tag{5}$$

where

D: depth of improvement in meters
W: mass of tamper in Mega grams
H: drop height in meters
n: empirical coefficient that is less than 1.0 (in this study n=0.35)

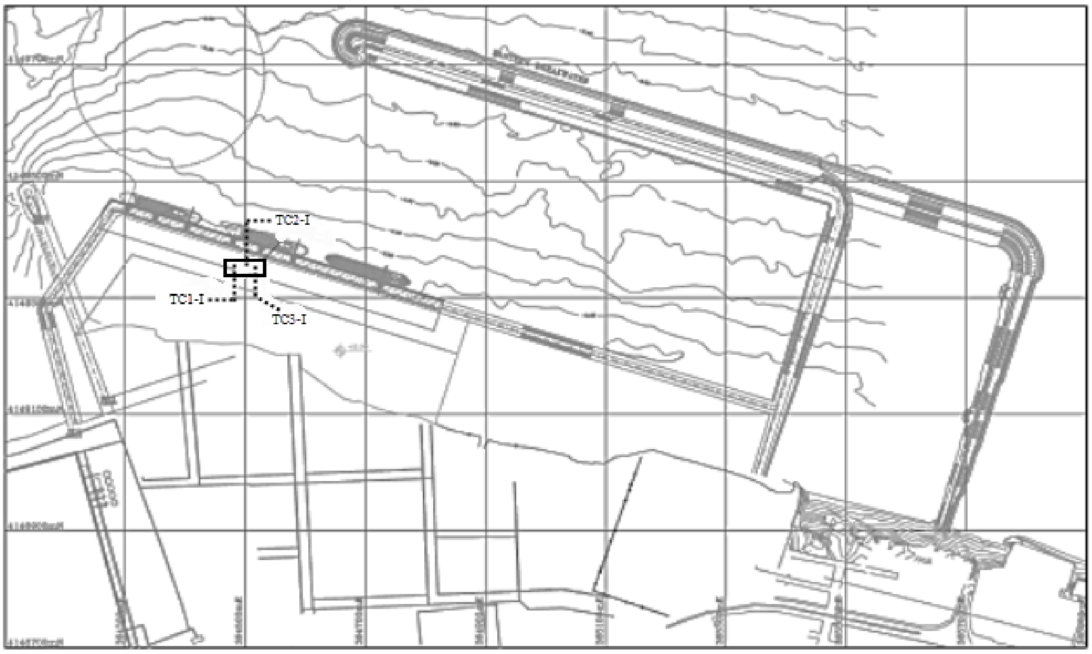
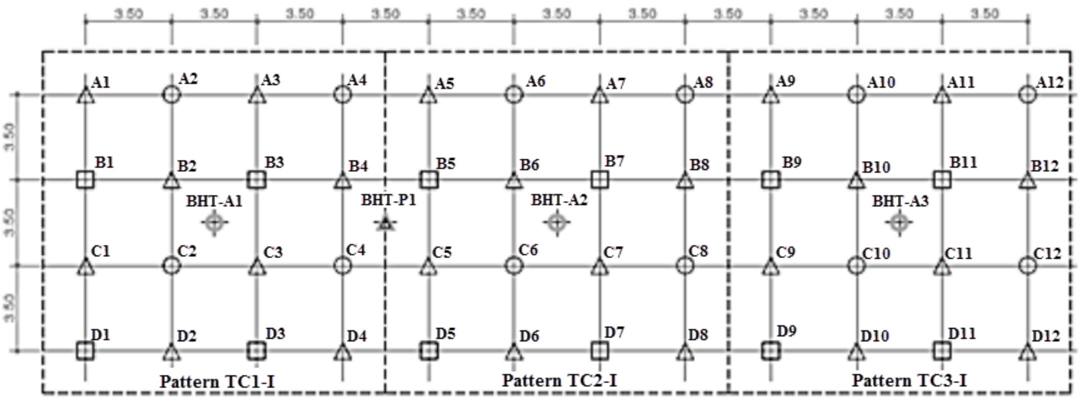


Figure 5. Location of three trial compaction patterns



* Borehole before compaction: BHT-P1

* Borehole after compaction: BHT-A1, BHT-A2, BHT-A3

Figure 6. Trial compaction patterns and impact points before and after compaction

Table 1. Trial compaction patterns adopted in current experiments

	Phase	Sign	Weigth (ton)	Heigth (m)	No. of drops	Grid spacing (m)
Pattern TC1-I	1	□	15	15	11	7.0
	2	○	15	15	9	7.0
	3	△	15	15	7	5.0
Pattern TC2-I	1	□	15	15	16	7.0
	2	○	15	15	14	7.0
	3	△	15	15	10	5.0
Pattern TC3-I	1	□	15	20	13	7.0
	2	○	15	20	10	7.0
	3	△	15	20	8	5.0

The empirical coefficient n attempts to account for factors that affects the depth of improvement other than the mass of the tamper and the drop height. n value has been found as reflection of site condition ranging from 0.3 to 0.8. The design evaluation values are summarized in Table 1.

Figure 7 shows a view of the dynamic compaction operation in Anzali harbor. A crater is formed at the impact point that may be up to 1.5 m deep. The craters are backfilled by enddumping rockfill into the craters. Several phases or passes of tamping performed across the site, depending upon the level of improvement required.

Following completion of the "high-energy" tamping, a low-energy or "ironing" phase is performed to compact the material in the craters and in the upper 1.5m of the reclaimed lands. According to the results of trial areas, compaction patterns in Anzali harbor site were selected and used as shown in the Table 1.

4. Testing

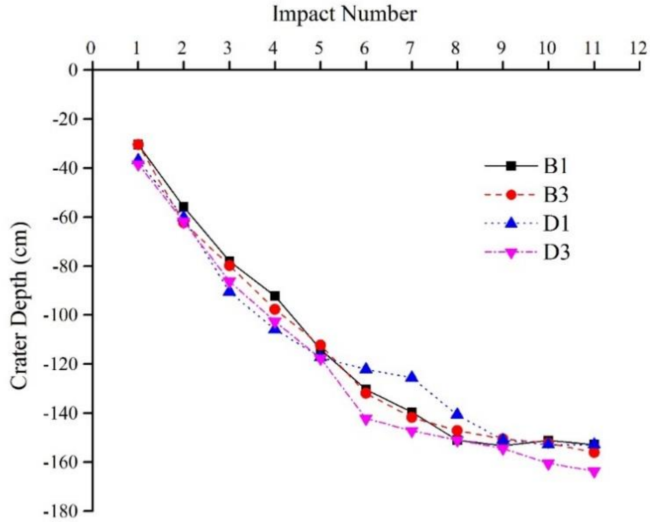
For evaluation of the efficiency of dynamic compaction process, some in-situ tests are performed before and after the compaction operations. The used tests were SPT and CPT. Moreover, crater depth in term of impact number and induced settlements were measured in trial areas.

Figures 8 to 10, show the crater depth variation with the impact numbers in TC1, TC2 and TC3 trial areas for 1, 2 and 3 phases respectively. For all these curves, the rate of bed settlement of crater reduces with increasing the impact numbers. For example, in 1, 2 and 3 phases from TC1 trial area after 11, 9 and 7 impact numbers, the rate decreases. It can be observed that initially the amount of ground (crater) settlement and compaction volume per blow follows a higher rate, but after certain impact number, the rate decreases.

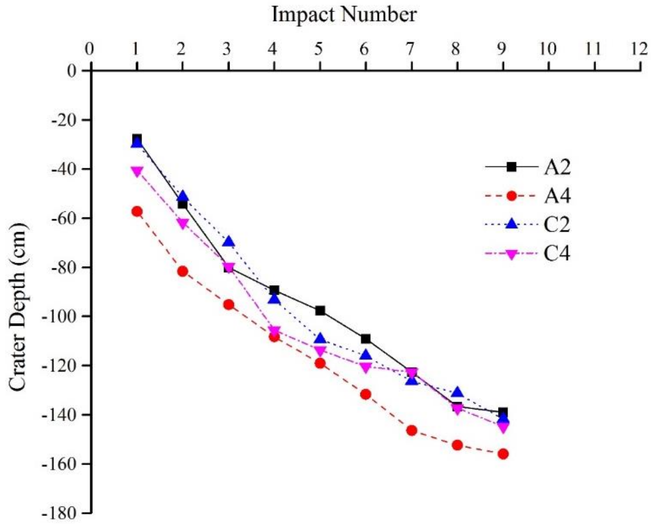
Figure 7. A view of dynamic compaction in Anzali harbor

Table 1. Adopted compaction patterns in Anzali harbor site

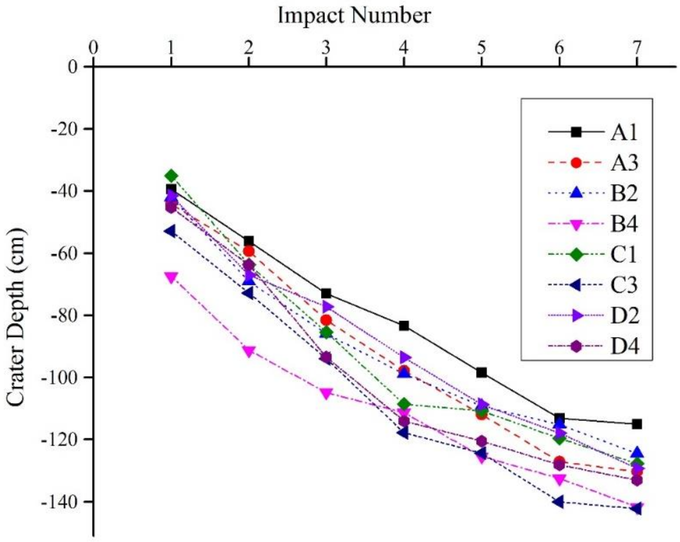
	Depth of improvement (m)	Phase	Grid spacing (m)	Pounder weight (ton)	Fall height (m)	Impacts number
Zone I-A	5	1	7	15	15	14
		2	7	15	15	12
		3	5	15	15	8
		ironing	Continues	10	5	3
Zone II-A	7.5	1	10	25	20	18
		2	10	25	20	16
		3	7	25	20	12
		ironing	Continues	10	5	3
Zone I-B	5	1	7	15	15	11
		2	7	15	15	9
		3	5	15	15	7
		ironing	Continues	10	5	2
Zone II-B	7.5	1	10	25	20	14
		2	10	25	20	12
		3	7	25	20	10
		ironing	Continues	10	5	2



a) first phase

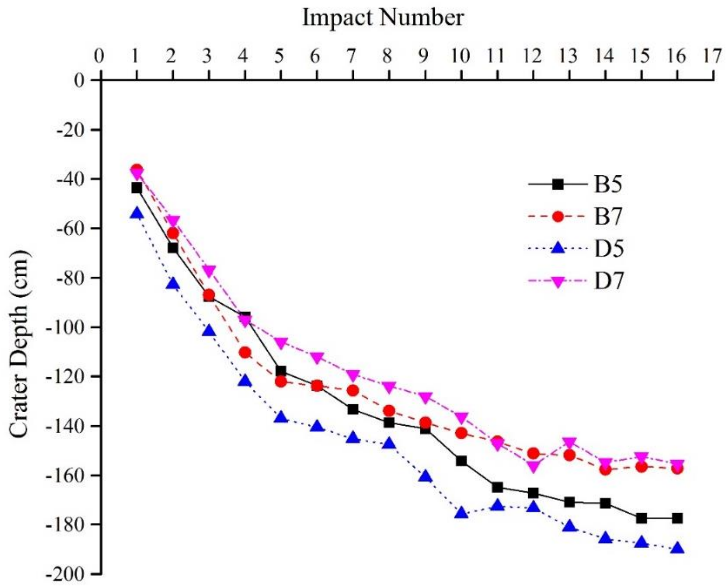


b) second phase

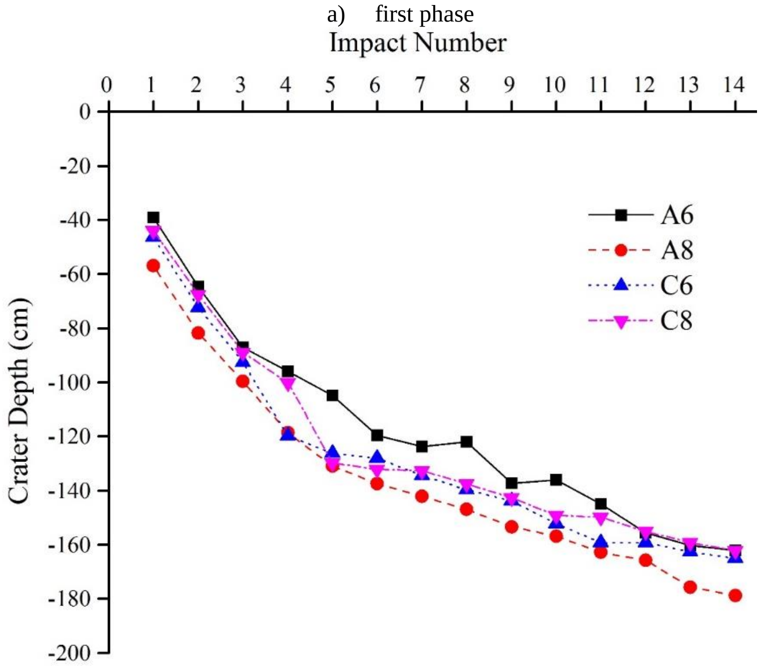


c) third phase

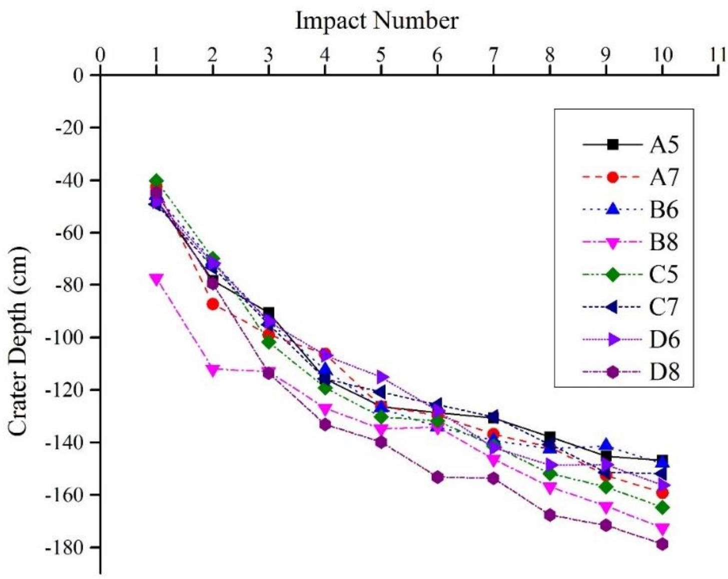
Figure 8. Crater depth in term of impact number in TC1 trial area



a) first phase

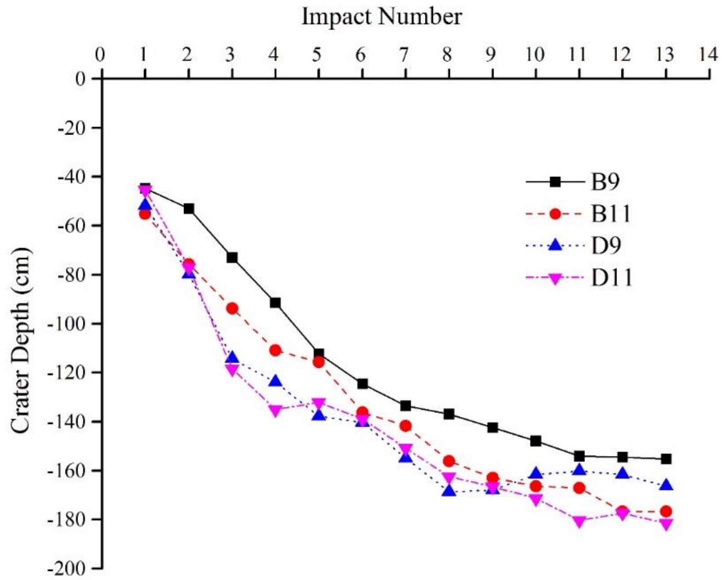


b) second phase

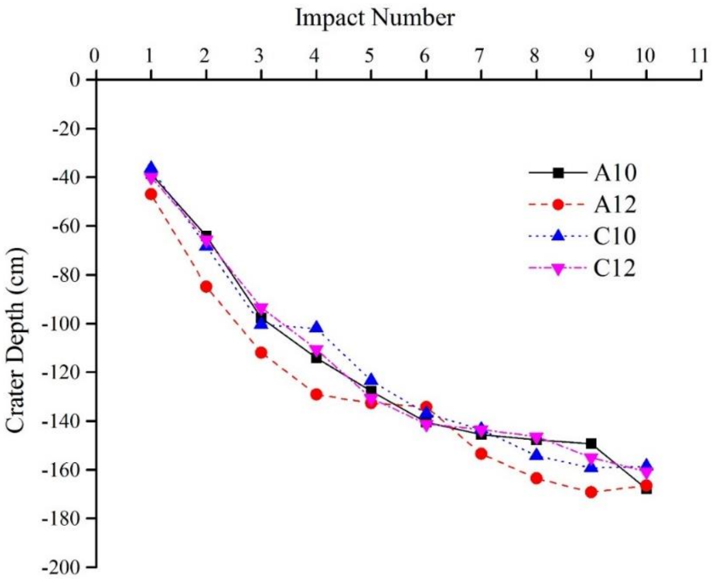


c) third phase

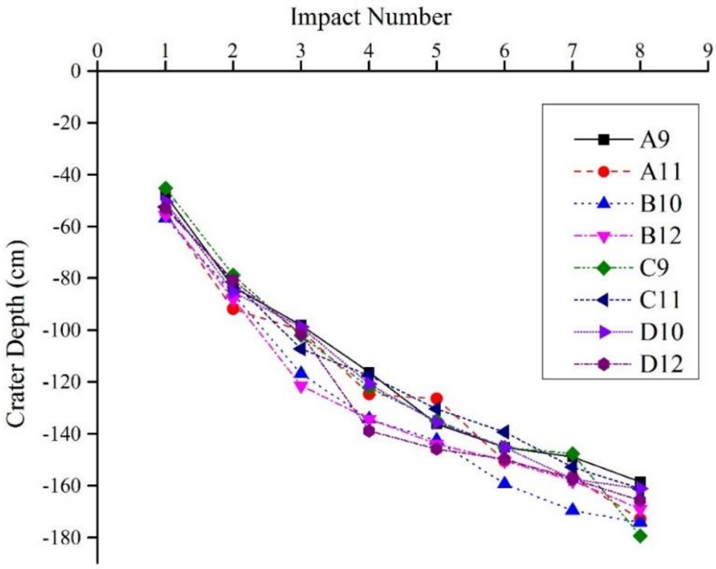
Figure 9. Crater depth in terms of the impact number in TC2 trial area



a) first phase



b) second phase



c) third phase

Figure 10. Crater depth in terms of the impact number in TC3 trial area

SPT is a most useful in-situ test for assessment of density and liquefaction potential of a soil layer. Based on the site seismicity studies, a liquefaction criterion was defined on earthquake hazard analysis, design base earthquake magnitude of 7.5 and peak ground acceleration of 0.3g and safety factor of 1.25. One of the important approach in treatment of filling material is to reach at SPT values that don't alarm liquefaction hazard anymore. In Figures 11 to 13, is shown the SPT values before and after the treatment for TC1, TC2 and TC3 trial areas, respectively. As can be seen from these figures, most of the SPT values measured are greater than those required to eliminate liquefaction potential. Few SPT numbers were lower than the target values like 4 to 6 m depth in TC1 that fine content in that depth is 45%. Subsequent liquefaction analysis incorporating the soil properties in terms of the SPT values obtained in the boreholes drilled during the post-compaction phase indicated that the liquefaction potential was significantly reduced.

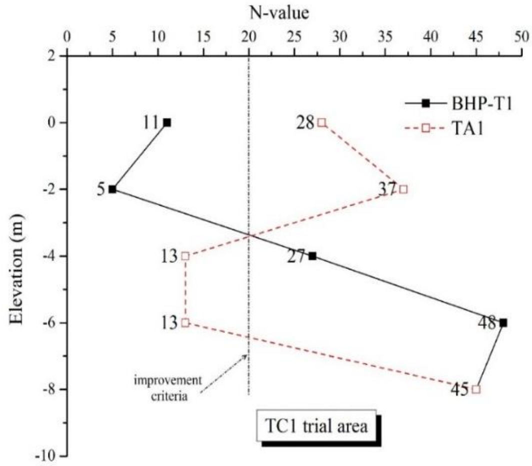


Figure 11. Effect of the treatment and reduction of the liquefaction potential for TC1 trial area

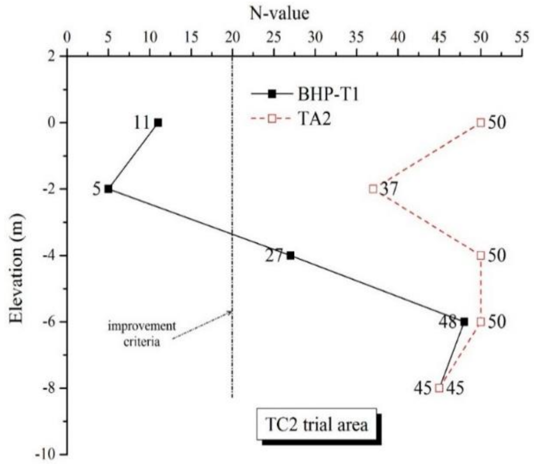


Figure 12. Effect of the treatment and reduction of the liquefaction potential for TC2 trial area

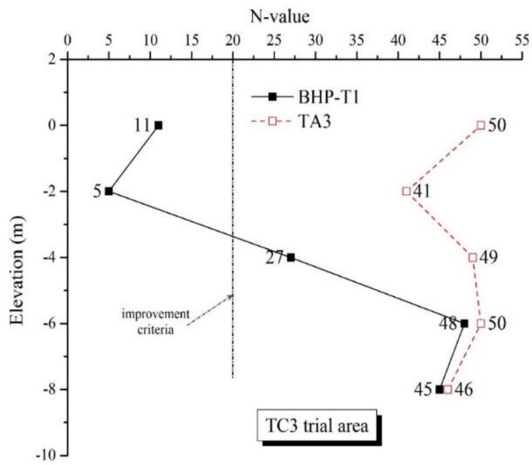


Figure 13. Effect of the treatment and reduction of the liquefaction potential for TC3 trial area

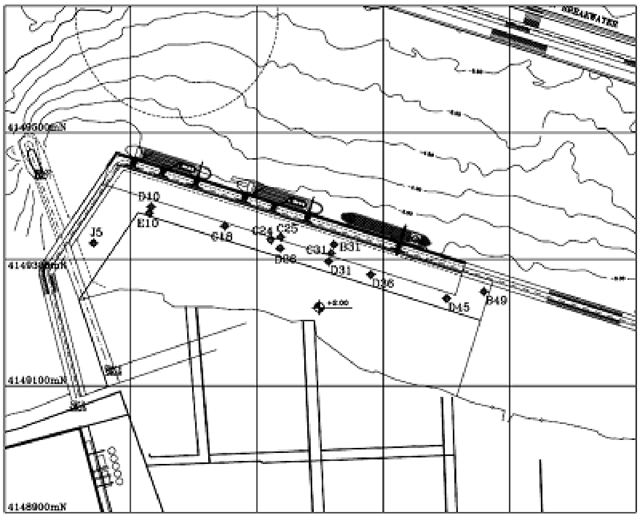


Figure 14. Location of the CPT tests

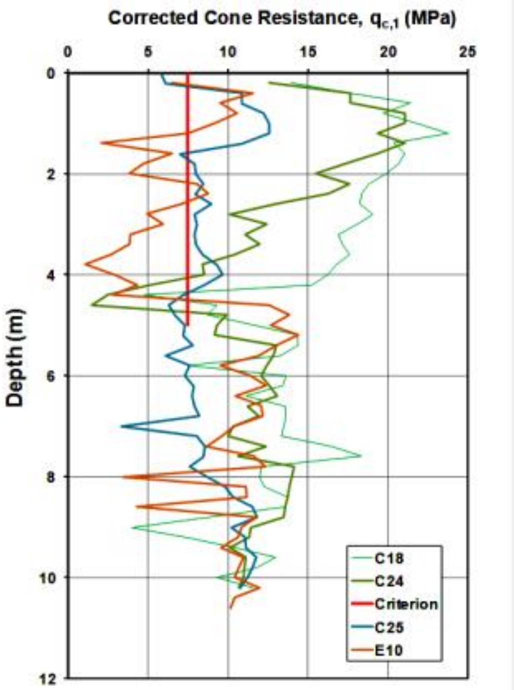


Figure 15. Results of the CPT tests before and after the dynamic compaction

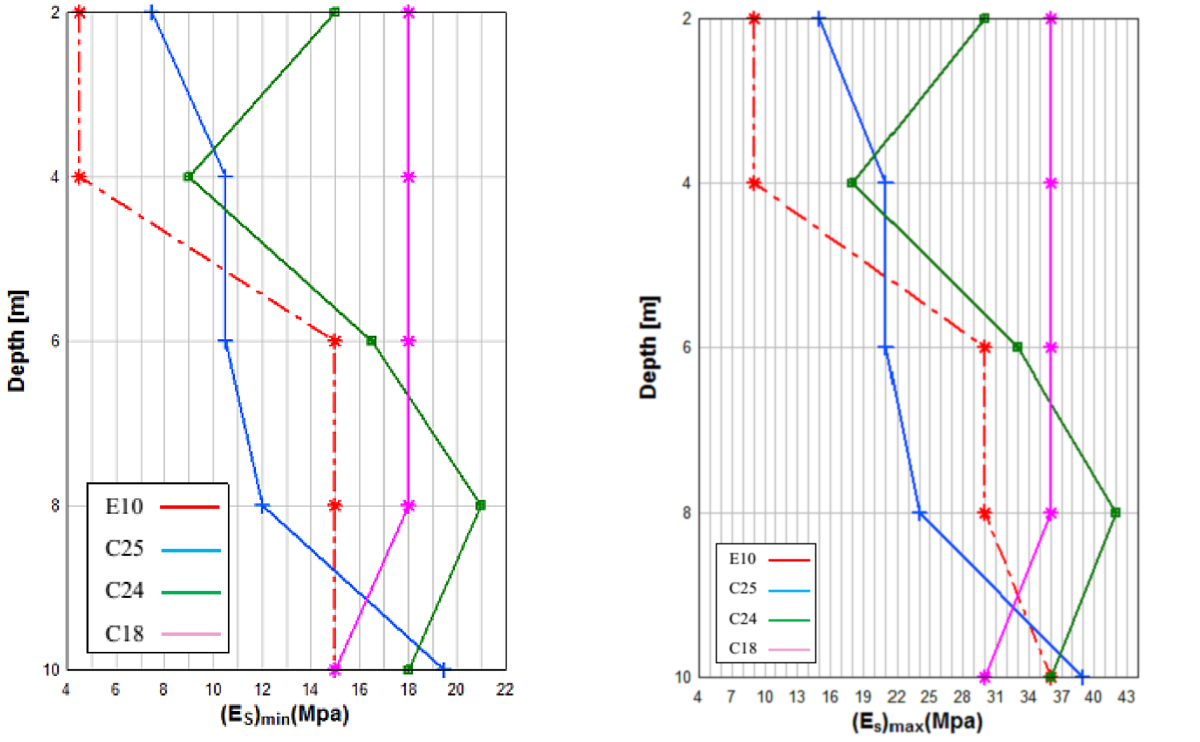
A series of CPT in-situ tests were carried out inside and outside of the compaction treated area to evaluate the compaction effects (Figure 14). The initial evaluation tests (E10 and C25) was conducted prior to the start of the dynamic compaction and the second tests (C18 and C24) was conducted following the completion of the first pass. The minimum amount of cone resistance from CPT test result is 7 MPa. In this section, only the CPT results inside the compaction treated area are presented and discussed. Figure 15 presents typical CPT results achieved before and after the dynamic compaction at treated area. Except for some spots, the cone resistance, qc, was significantly improved after compaction. For topsoil near the ground surface, cone resistance values were improved up to 2 times after the compaction.

Young's Modulus can be calculated from the CPT results according to the Table 2. For silty sand and based on the results, young modulus is calculated from the Eq. (6). Figures 16 shows a typical variation of the Young's modulus and depth before and after the improvement. For determination of the Young's modulus, the CPT profiles are more efficient than the SPT values, however, it suffers from the disadvantage of not providing a soil sample for visual classification. On most projects, an exploration program which combines the use of the SPT and the CPT results would be desirable [16].

$$E_s = (1.5{\sim}3)q_c \qquad (6)$$

Table 2. Correlation between the Young's modulus and the CPT results

Correlation	Soil Type	Reference
$E_s = 1.5q_c$	Silts, Sands	Meyerhof and Fellenius [17]
$E_s = 3.5q_c$ Plain strain condition $E_s = 2.5q_c$ Axisymmetric condition	Sands, Silty Sand	Schmetmann [18]
$E_s = (1\sim2)q_c$	Silts, Sandy Silt	Bowles [19]
$E_s = (1.3\sim1.9)q_c$	Silty Sand	Bachelier and Parez [20]
$E_s = 1.5q_c$ for $q_c > 4$MPa $E_s = (1.5\sim1.8)q_c$ for $4 > q_c > 2$ $E_s = (1.8\sim2.5)q_c$ for $2 > q_c > 1$ $E_s = (2.5\sim3)q_c$ for $1 > q_c > 0.5$	Silty Sand and Clayed Silt	Mitchell and Gardner [21]



(a) (b)

Figure 16. Young's modulus variation with depth before and after the dynamic compaction; a) $E_{s(min)}$; and b) $E_{s(max)}$

5. Conclusions

Land reclamation from sea is being carried out in many countries to provide required land for construction of infrastructures. Engineering geological studies is necessary for site the investigation before reclamation and during improvement of reclaimed land. Engineering geological studies in two phases were carried out for land reclamation project in Anzali harbor region. In first phase different reconnaissance tests on sea floor and on available filling materials were performed to evaluate site conditions for filling the sea and reclamation. In first step of second phase, engineering geological characteristics of reclaimed land were evaluated to understand usability of land for construction of infrastructures. In-situ test results in this step showed that reclaimed land in Anzali harbor region is susceptible to liquefaction hazard and excessive settlement potential. Improvement of the reclaimed land was necessary due to the results of this step. Dyntamic compaction was selected for improvement of reclaimed land from the Caspian sea. Second step of studies focused on improvement of reclaimed land to control effectiveness of the dynamic compaction. Results of the in-situ tests in reclaimed land showed that the liquefaction hazard potential has been mitigated and bearing capacity of ground has been reached desirable level after the dynamic compaction.

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