Al-Azhar University Civil Engineering Research Magazine (CERM)
Vol. (44) No. (3) october . 2022

Assessment of Ground Improvement by Dynamic Compaction in Saturated Loose Sandy Soil Formation

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ملخص البحث:

يعتبر الضغط الديناميكي أحد أكثر طرق التكثيف شيوعًا المستخدمة في جميع أنحاء العالم لتحسين التربة. يستخدم الضغط الديناميكي لتعزيز خصائص التربة وبالتالي زيادة قدرة تحمل التربة وتقليل فرص حدوث تسييل التربه التي تمثل بشكل أساسي خطرًا رئيسيًا في التربة الحبيبية السائبة المشبعة. في هذا البحث ، يتم استخدام الضغط الديناميكي لتكثيف طبقة من التربة الرملية المشبعه بالمياه بعمق 4 أمتار على مساحة سطح كبيرة تبلغ 1.545.000 متر مربع في مشروع في المملكة العربية السعودية. تم استخدام اختبار مينارد لمقياس الضغط (PMT) واختبار الاختراق المخروطي (CPT) لتقييم فعالية عملية الضغط الديناميكي. يصف هذا البحث بإيجاز أعمال تحسين التربه ونتائج اختبارات التقييم التي أجريت في الموقع. بالإضافة إلى ذلك ، اقترح المؤلفون علاقات رابطه بين نتائج CPT و PMT وتمت مراجعتها مع نتائج الابحاث المنشورة السابقة التي تربط CPT بـ PMT للتحقق منها.

Abstract:

Dynamic compaction is considered one of the most popular densification methods used worldwide for soil improvement. Dynamic compaction is used to enhance the soil properties and thus increase the soil bearing capacity and minimize the liquefaction potential that is mainly a major risk in saturated loose granular soil. In this paper, dynamic compaction is used to densify a 4 m deep loose sandy soil layer over a large surface area of 1,545,000 m^2 in a project in Saudi Arabia. The Menard Pressuremeter Test (PMT) and the Cone Penetration Test (CPT) are used to evaluate the effectiveness of the dynamic compaction process. This research briefly describes the ground improvement works and evaluates the results of tests carried out in the site. In addition, correlations between CPT and PMT results were suggested by the authors and reviewed with previous published literature correlating CPT to PMT for verification.

Keywords: dynamic compaction, loose sand, cone penetration test, pressuremeter test, liquefaction.

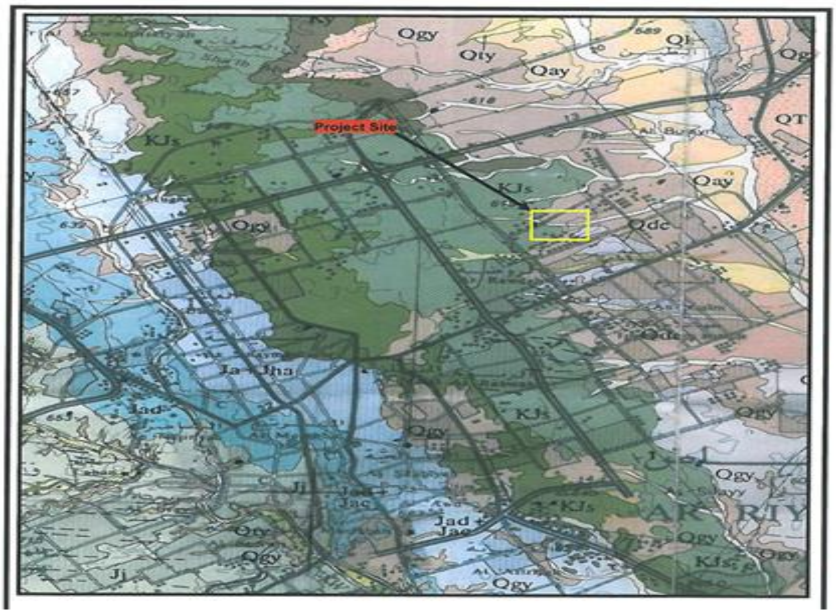
1- Introduction

Dynamic compaction (DC) is one of the most commonly used ground improvement techniques where it is mainly used as a densification method to improve soil properties and to mitigate the hazard of liquefaction present in any saturated loose granular soil formation [1, 2, 3]. Ground improvement occurs by the process of densifying the soil by using external compactive effort where basically steel or concrete pounder of heavy weight around 6–30 tons is dropped from a certain height around 3–20 m. The repeated dropping of the pounder follows a predetermined progressive grid pattern carried out in several phases. The DC technique was first developed by Menard in the 1970s [4]. The dynamic compaction method is very suitable for the densification of loose granular soil such as sandy materials and granular fills, whether the soil is saturated or unsaturated. However, it is only utilized on a limited number of cohesive soils soil, such as silt or clay [1]. Recent studies indicate that DC can also be applied to improve fine grained soils only by providing pre- installed drainage systems such as wick drains. The drains help relieve the excess pore pressures induced during DC, and facilitate repeated impacts and densification [5].

In this research, the ground improvement using dynamic compaction of a saturated loose sandy soil formation in Saudi Arabia is evaluated. The parameters of DC, including the weight of the pounder, the drop height, the grid spacing, the number of phases, were determined based on the site geological conditions and after a calibration work. Assessment of the liquefaction hazard mitigation was carried out to study the effect of the dynamic compaction on the saturated loose sands. The densification results were evaluated using two field tests: Cone penetration test (CPT) and Menard pressuremeter test (PMT). A correlation between the CPT results with the PMT ones is also provided in this research as it a helpful tool for soil investigation and design.

2- Geology of the Site and Subsurface Charaterization

The project site is located in the kingdom of Saudi Arabia; about 10 km away from the Dammam–Riyadh new Expressway and its area is around 1,545,000 m^2. According to the Saudi Arabia geological map, the geological formation of this area consists of the KJS formation that is mainly limestones and the Qay formation which consists of flood plain deposits and basin alluvium. Also based on the hydrological assessment carried out at the site project, it was found that the site is bisected by major Wadi. Figure 1 shows the geological map and the site location of the area under study.



Qay Flood Plain Deposits   KJS Limestone Formations

Figure 1 Geological Map at the Site Location

The kingdom of Saudi Arabia has been divided into seven regions of seismicity following the Uniform Building Code, UBC 1997 [6] and based on the Peak Ground Acceleration (PGA) values calculated for 50 years service lifetime with 10% probability of being exceeded. Accordingly, and based on the Saudi building code (SBC 301- Seismic Design criteria) and on the earthquake hazard analysis, the project site is classified as Region 1 with a design base earthquake magnitude of 5.2 and peak ground acceleration is 0.08g.

The site soil conditions were determined by carrying out a soil investigation campaign comprising boreholes with different depths and performing Standard Penetration Tests to determine the soil relative density. Figure 2 presents a typical soil profile with average SPT- N values along soil depth at the site location. The soil condition at this site is represented by loose poorly graded sand to a depth of about 4.0 m. The soil relative density increases with depth and the loose sandy layer is thus followed by medium dense sand with silt till 12 meters depth then finally a dense silty sand layer shows till end of borehole. The groundwater level was encountered at an average depth of 1.0 m below the ground level.

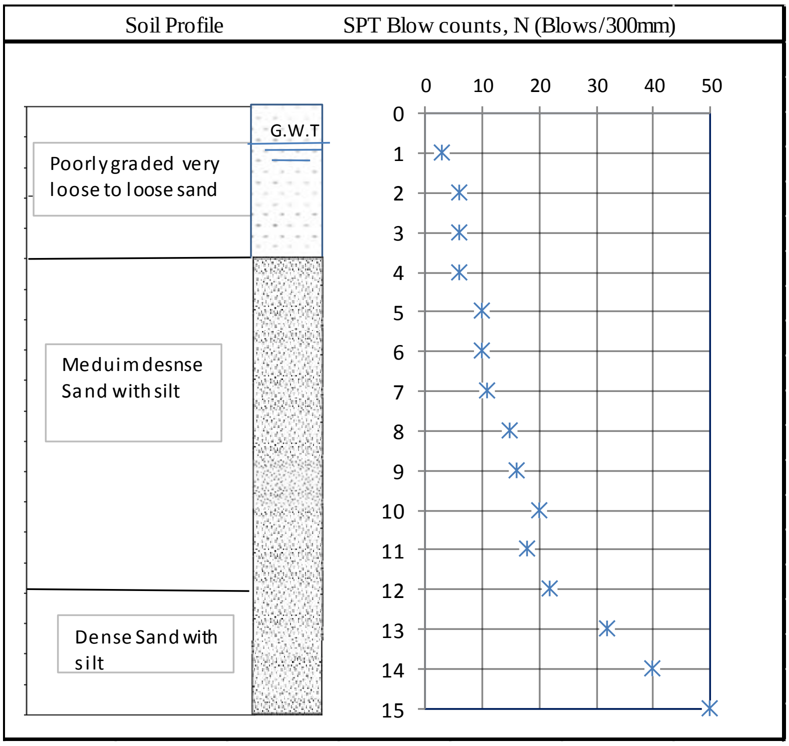


Figure 2 Soil profile and SPT Results for the site under study

Based on the soil lithology and the presence of saturated loose sand layers that is vulnerable to liquefaction, several improvement techniques were investigated such as: spreading and compacting crushed stones, vibro-compaction, vibro-replacement, dynamic compaction, etc.

The aims of soil improvement are to reduce post-construction settlements (total and differential), increase the bearing capacity, and to mitigate the risk of liquefaction. The Advantages of ground improvement were also to eliminate the need for deep foundations or the need for soil replacement and to satisfy the overall stability of the buildings with adequate factors of safety.

The first tried improvement technique was the compacted crushed stones method. A trial area was dedicated on site to study the efficiency of this approach. Unfortunately, the results of the soil improvement using the crushed stones technique were not satisfactory and showed that this technique is not suitable for the prevailing subsurface conditions. Accordingly, and after further study and analyzing the quality control tests results, the dynamic compaction technique was chosen to be adopted.

3- Dynamic Compaction Method Statement

Dynamic compaction is usually applied for granular soils with up to 30-35% fine content, it is well adapted to large areas, and it provides uniform ground conditions all over the site. The basic equipment consists mainly of a heavy mobile crane complete with a set of interchangeable pounders. Cranes are able to lift up to 35 tons pounders up to 35 meters height and as such deliver an energy equivalent to 1200 ton/meter in a single blow. The

impact of the falling weight results in the generation of high energy shear and surface waves that result in the densification of the fill through the re-arrangement of the grains and thus immediate densification of granular soils.
The dynamic compaction parameters were selected according to the nature of the soil, the thickness of the layer to be improved and other criteria such as the structural requirements. Note that the soil improvement parameters couldn't be totally predefined. The calibration work was the best guide to define the energy; however, it was necessary to adjust compaction energy during execution subject to local ground conditions.

3.1- Calibration Area Tests and Dynamic Compaction Pattern

The site was raised by 1.5 m above the groundwater level in order to ensure the safety and stability of the soil improvement equipments. The platform material consists of well graded medium to coarse clean sand with fines content less than 20% and clay content less than 1%. Samples were collected from the backfilling materials for laboratory tests. Granular backfill materials with low chloride and sulfate levels were used as structural backfill. Figure 3 (a) and (b) shows some views of the dynamic compaction process at the site location.

(a)

(b)

Figure 3 Dynamic Compaction Equipments at the Site Location a) The Crane, b) The Craters

Two field tests were carried out to study the effect of dynamic compaction on the soil conditions: Cone Penetration Test (CPT) and Menard Pressuremeter Test (PMT). The main parameters affecting the dynamic compaction process that were determined from the calibration area tests were: a) the number of blows per print, b) the drop height, c) the type and weight of the pounder, and e) the number of phases needed.
Based on calibration area tests results the following dynamic compaction parameters were applied:

- Grid spacing = 6 mx6 m
- Weight of pounder= 15-18 tons.
- Height of Drop = 15 m.
- 6 blows per print of phase 1
- 4 blows per print of phase 2.

The site was divided into segments of 7500 m^2 each. The Steps for executing the dynamic compaction process were as follows:

- Leveling and surveying before the dynamic compaction DC works commencement.
- Setting out of DC phase 1 location.
- Execution of DC phase 1 using the parameters extracted from the calibration area.
- Backfilling of DC prints and leveling.
- Setting out of DC phase 2 locations.
- Execution of DC phase 2 using the parameters extracted from the calibration area.
- Backfilling of DC prints and leveling.
- Execution of final phase, if necessary.
- Backfilling of DC prints and leveling.
- Roller compaction of the final ground improvement level.

Figure (4) shows a schematic layout of Dynamic compaction carried out at the site.

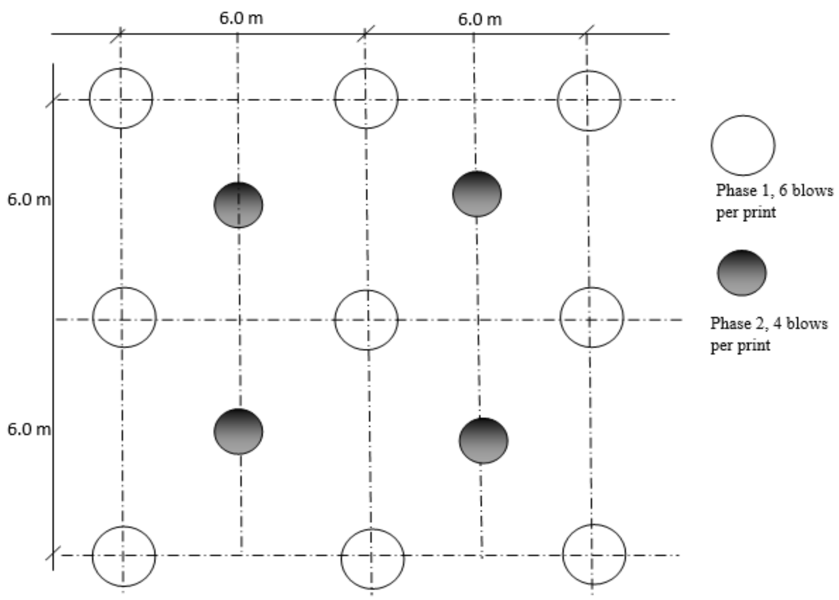


Figure 4 Schematic layout of Dynamic compaction carried out at the site

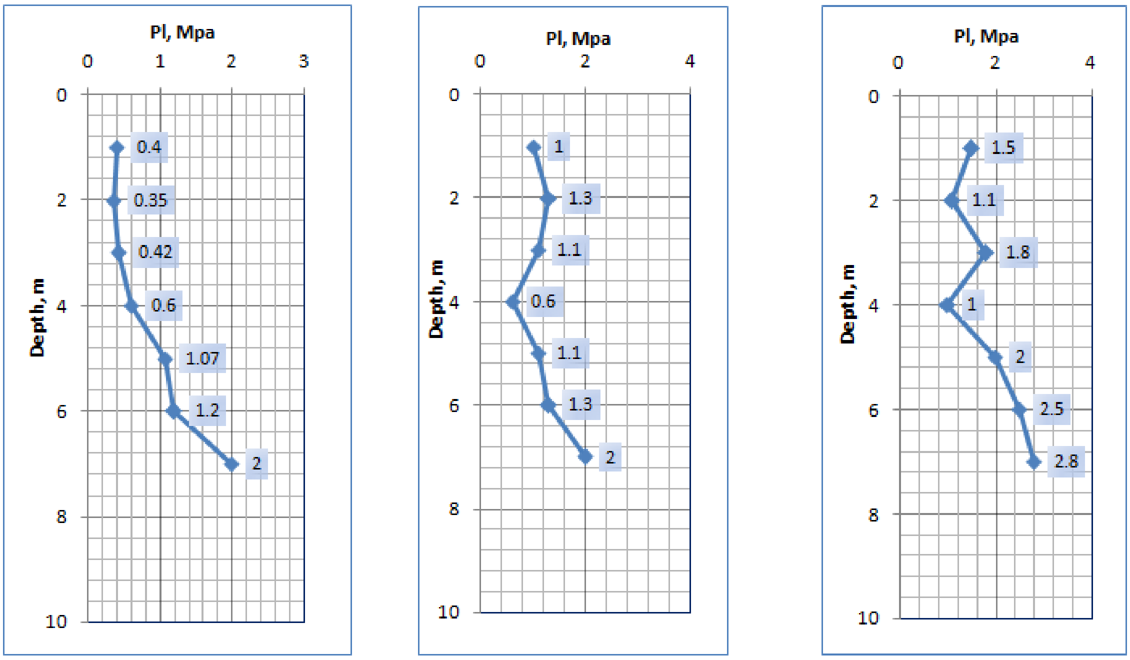
3-2 Results and Analysis

Only Pressure meter tests (PMT) and cone penetration tests (CPT) were utilized for evaluating the effectiveness of dynamic compaction. The parameters recorded from the PMT were the limit pressure, Pl and pressuremeter modulus, Em, while the cone penetration resistance, qc was obtained from the CPT.

The Post-treatment quality control tests were performed for the whole site area as follows:

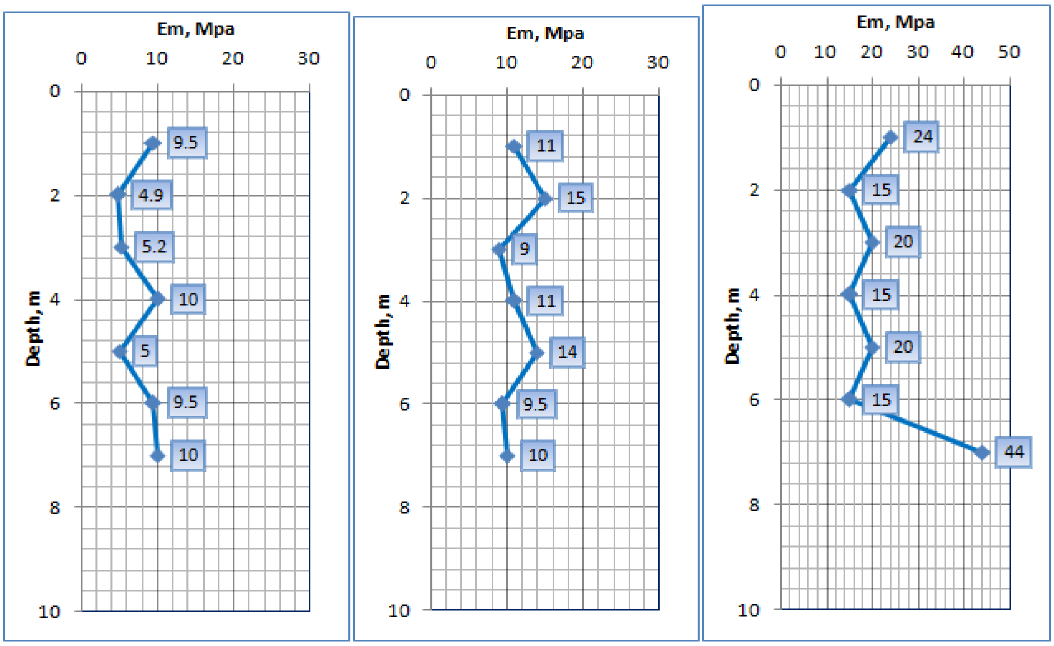
- 1 Pressure-meter test (PMT), down to 10 m of depth or refusal, each 5000 m^2 of the treated area.
- 1 Cone Penetration Test (CPT), down to 10 m or refusal, each 2500 m^2 of the treated area.

Figures 5, 6, and 7 show the values of the limit pressure, the pressuremeter modulus of the PMT and the cone resistances of the CPT versus depths before and after DC respectively.



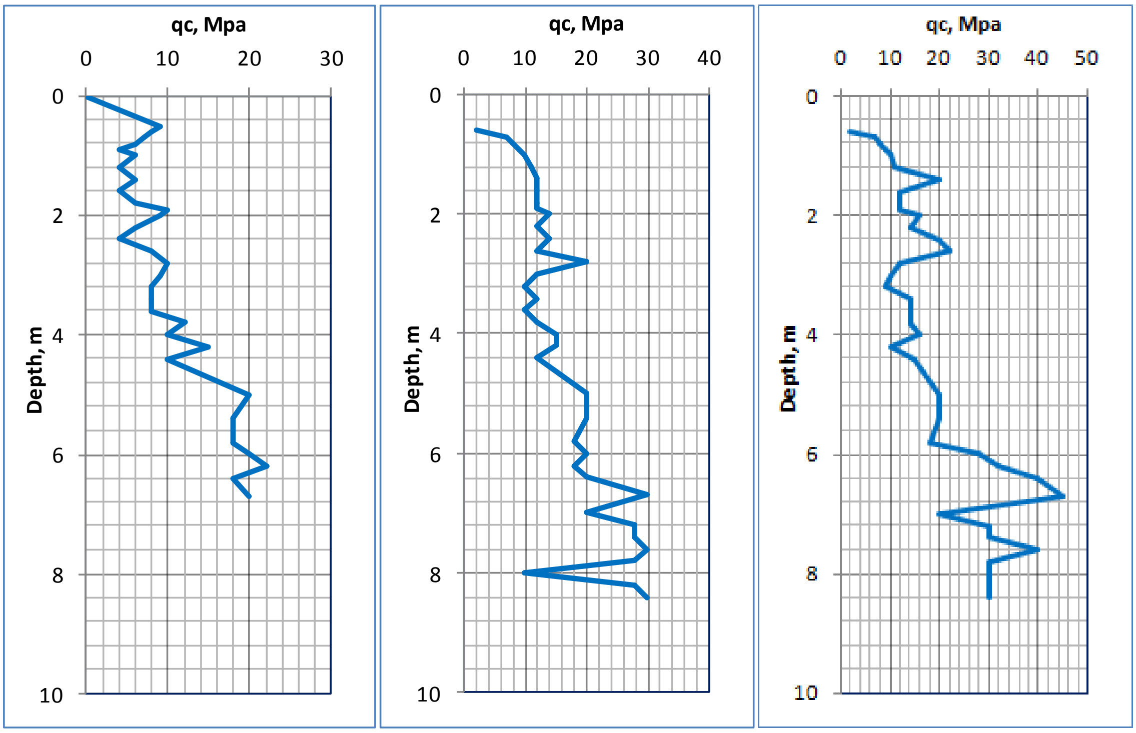
(a) (b) (c)

Figure 5 PMT- Limit Pressure, Pl Values a) Before D.C. b) after D.C Phase 1 c) After D.C. Phase 2



(a) (b) (c)

Figure 6 PMT- Menard Modulus, Em Values a) Before D.C. b) after D.C Phase 1 c) After D.C. Phase 2



(a) (b) (c)

Figure 7 CPT- Cone penetration resistance, qc values a) Before D.C. b) after D.C Phase 1 c) After D.C. Phase 2

The ground improvement works carried out at the site aimed to satisfy the design criteria requirements as follows:

- Safety against shear failure: Bearing capacity of 150 Kpa.
- Maximum allowable settlement of 25mm.
- Differential settlement as an angular distortion tolerable limit: 1/500.
- Adequate factor of safety against liquefaction considering the seismic zone of the area in accordance with the Uniform Building Code (UBC) and the Saudi Building Code (SBC)., (F.O.S. = 1.30).

It is obvious from figures 5, 6 and 7 the significant increase in the values of soil parameters Pl, Em, and qc after the dynamic compaction process which indicates the improvement in the soil properties which is a need to satisfy the project design criteria mentioned in the previous section.

Accordingly, the values recorded from CPT and PMT after DC were used to calculate the soil bearing capacity, the expected settlements/differential settlements under footings, as well as the factor of safety against liquefaction.

The calculations of the bearing capacities and settlements under footings before and after DC are not included here as it is not the concern of this research. However, it is worth mentioning that the values of the bearing capacity as well as the post-treatment settlement/differential settlements met the design criteria. The same improvement was achieved regarding the liquefaction potential risk. The factor of safety against liquefaction was calculated based on the CPT results before and after DC [7]. The effect of Dynamic Compaction on the Soil Liquefaction Resistance is shown in Figure 8 and compared with the liquefaction criteria of the project.

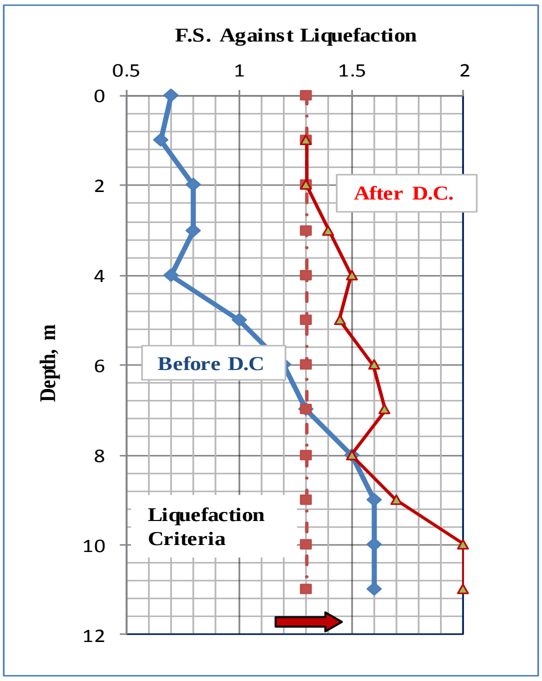


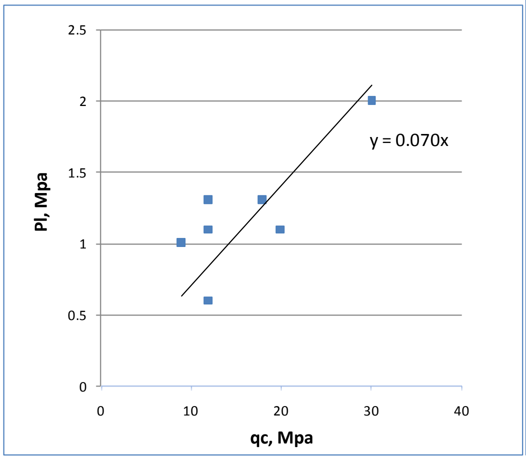
Figure 8 Effect of Dynamic Compaction on the Soil Liquefaction Resistance

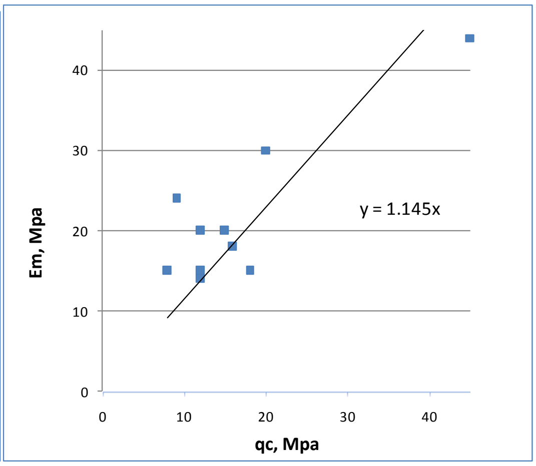
The correlation between PMT-Pl values and PMT-Em with CPT-qc values for sandy soil formation after DC is given in Figure 9-a and 9-b respectively. The empirical equations suggested, based on the data of this research, are expressed as follows:

$$Pl\ (Mpa) = 0.07\ qc \qquad (1)$$

$$Em\ (Mpa) = 1.145\ qc. \qquad (2)$$

To verify the proposed correlations, a review with previous published literature correlating CPT to PMT was carried out [8, 9, 10, and 11]. Attention was taken to compare correlations created for the same soil type and soil conditions. A summary of the comparison is shown in Table 1. It is shown from the summary table that the proposed correlations are in good agreement with the ones derived earlier for the same soil conditions.





(a) (b)

Figure 9 Correlation between a) PMT-Pl and b) PMT-Em with CPT-qc values for sandy soils after Dynamic compaction

Table 1 Previous Correlations Between PMT Results (Em and Pl) and CPT Results (qc) for Various Soil Formations as Suggested by Different Researchers.

Empirical Correlation	Soil Type	Reference
Pl (MPa) = 0.2 to 0.08 qc	Sand and gravel	Baguelin F., et al , 1978 [8]
Pl (MPa) = 0.1 qc Em (MPa) = 1.05 qc	Dense sand	Schmertmann, J. H. et al 1978 [9]
Pl (MPa) = 0.2 qc Em (MPa) = 1.5 qc	Loose sand	
Pl (MPa) = 0.11 qc Em (MPa) = 1.15 qc	Sand	Briaud, 2013 [10]
Pl (MPa) = 0.2 qc Em (MPa) = 2.5 qc	Clay	
Pl (MPa) = 0.14 qc Em (MPa) = 1.7 qc	Dense sand	Fayed A.L., 2014 [11]
Pl (Mpa) = 0.07 qc Em (Mpa) = 1.145 qc	Compacted Sand	Correlation Based on this Current Research

4- Conclusions

This paper presents the ground improvement works that was carried out using dynamic compaction for a project located in Saudi Arabia. The site conditions included a saturated 4.0 thickness layer of loose sand which was vulnerable to liquefaction. By analyzing the dynamic compaction field results, the following conclusions were obtained:

1. Dynamic compaction technique is able to improve the geotechnical properties of the very loose to loose granular soil, with high ground water conditions, to great depths (up to 4.0m in this research).
2. Using both PMT and CPT for the dynamic compaction quality control is crucial in measuring the effectiness of the method applied to overcome the shortcomings of using only one type of testing.
3. The results of tests show that the dynamic compaction is useful to increase the bearing capacity, lower the settlement values to the allowable limits for shallow foundations, and mostly reduce the liquefaction potential.
4. The proposed correlations between PMT and CPT suggested in this research (Pl (Mpa) =0.07 qc and Em (Mpa) =1.145 qc) are verified with previous correlations available in the literature review and shows good agreement, specifically when compared with soil with same type and condition.

5- References:

1. Nashed R., Thevanayagm S., Marting G.R., 2009 “Dynamic compaction in saturated sands and silty sands: Results”. Proceedings of the Institution of Civil Engineers, 162, No.2, 81-92.

2. Feng, S. J., W. H. Shui, K. Tan, L. Y. Gao, and L. J. He., 2011 “Filed evaluation of dynamic compaction on granular deposits”. Journal of Performance of Constructed Facilities, 25(3): 241–249.

3. Leonards, G. A., R. D. Holtz, and W. A. Cutter, 1980 “Dynamic compaction of granular soils. Journal of Geotechnical Engineering, 106(1): 35–44.

4. Menard, L.; Broise, Y., 1975 “Theoretical and practical aspects of dynamic consolidation”. Geotechnique Vol. 25, Pages 3–18.

5. Joon-Shik Moon, Hyuk Sang Jung, Sungjune Lee and Su-Tae Kang, 2019 “Ground Improvement Using Dynamic Compaction in Sabkha Deposit”. Journal of Applied Science, No. 9, 2506.

6. UBC, Uniform Building Code, International Conference of Building Officials, 1997,Whittier, California.
7. Youd, T. L., Idriss, I. M., Andrus, R. D., Arango, I., Castro, G., Christian, J. T., Dobry, R., Liam Finn, W. D., Harder L.F., J., Hynes, M. E., Ishihara, K., Koester, J. P., Liao, S. S. C., Marcuson III, W. F., Martin, G. R., Mitchell, J. K., Moriwaki, Y., Power, M. S., Robertson, P. K., Seed, R. B., and Stokoe II, K. H., “Liquefaction resistance of soils: Summary report from the 1996 NCEER and 1998 NCEER/NSF workshops on evaluation of liquefaction resistance of soils.” Journal of Geotechnical and Geoenvironmental Engineering, Vol. 127, No. 10, 2001, pp. 817-833.

8. Baguelin F, Je´zeque´l JF, Shileds DH, 1978. The pressuremeter and foundation engineering. Trans Tech Publications, Clausthal-Zellerfeld, Germany

9. Schmertmann, J. H., 1978, “Guidelines for Cone Penetration Test Performance and Design,” Report No. FHWA – TS – 78-209, U.S. Department of Transportation, Federal Highway Administration, Washington, D.C.

10. Briaud JL, 2013 “The pressuremeter test: expanding its use, Menard Lecture”. Proceedings international conference on soil mechanics and geotechnical engineering, Paris, Vol 1, pp 107–126.

11. Fayed, A., Correlations between CPT and PMT for Semi-Carbonate Sand Improved by Dynamic Compaction, Al-Azhar University Civil Engineering Research Magazine (CERM), Vol. () No. (4) October, 2014.