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Research Article

EXPERIMENTAL STUDY OF EFFECTS OF SYNAMIC COMPACTION ON GEOTECHNICAL PARAMETERS IMPROVEMENT OF COARSE GRAIN SOLIS

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ABSTRACT
Dynamic compaction is one of the most common methods of improving loose coarse grain soils. In this method compaction rate and bearing capacity of the soil are increased through heavy tamping on its surface. Moreover the application of this method is useful to reduce or eliminate liquefaction potential of soils. Wide lands of Aslalooyeh have been reclaimed from the sea which has been improved by dynamic compaction method. The aim of present investigation is experimental study of above mentioned dynamic compaction. Hence soil of the place was transferred to the laboratory and some samples were remolded of it. After dynamic compaction, improvement rate and strength increase were studied through density measurement and loading. Tests used to study effects of dynamic compaction are plate load test and density test. The main objective of present study is to investigate the effects of applied energy and underground water on compaction rate of soils. Results of present study indicated increase of soil engineering parameters such as unit weight, modulus of deformation and subgrade reaction modulus and also comparing values of these parameters after dynamic compaction in the laboratory and field.

Keywords: *Dynamic Compaction, Coarse Grain Soil, Asalooyeh, Plate Load Test*

INTRODUCTION

Use of dynamic compaction for loose soil improvement has been increased considerably in recent decades. In this method, body masses are propagated in soil mass through releasing heavy tempers on the soil surface, and it forms denser contexture through changing arrangement of soil grains. This, results in improving soil shear strength and increased bearing capacity. The project of land reclamation from the sea has been carried out with approximate dimensions of 300×5000 in Asalooyeh (located at South part of Iran), due to necessity of proximity of different petrochemical units of "Parse Jonubi", and necessity of providing required lands. According to the accessible information, this project is the largest project of land reclamation from the sea in the country.

Embankment mass has loose condition and it should be compacted to increase bearing capacity and decrease liquefaction potential. Special patterns and methods are used in these operations to reach soil layers compaction to considered rate. Improvement rate and effective depth of dynamic compaction are influenced by different factors. Present study was conducted in laboratory on empirical samples to examine influencing way of dynamic compaction and its influential factors.

The aim of present study is experimental investigation of the effect of energy on improvement of coarse grain soils in dynamic compaction method and comparing results of laboratory and the field.

Review of Literature

Different studies have been carried out to investigate dynamic compaction in laboratory with employment of physical models, until date. Studies such as Pouran *et al.,* (1992) and Oshima and Takada (1994) are of this type. Chao *et al.,* (1994) in their experimental study, investigated the effects of tamping distances on effectiveness of dynamic compaction.

Laboratory Operations

Basic Soil Preparation

A few amount of soil used for land reclamation from the sea in Asalooye was transferred to the laboratory and investigation studies were carried out on them. The origin of mentioned soil was mainly coarse grain alluvial deposits existing in alluvial cones of Northern heights of the project site. These sedimentations

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had hill condition and removing them can provide plain lands to establish other sectors of the Petrochemical Company. Above mentioned sedimentations were mixed combination which had fine clay particles and particles bigger than 50cm. Figure (1) shows gradation curve of materials passing from 3 inches sieve for underlying soils. It can be seen that, these soils contain 20% fine materials, 40% sand and 40% gravel and cobble. Unified classification of above mentioned materials is mainly GM. It is of course worth mentioning that, if we consider cobbles and stone pieces in the gradation, then fine materials of soil mass will be less than 10%. In this study, a basic soil was determined from underlying soil and tests were carried out on it.

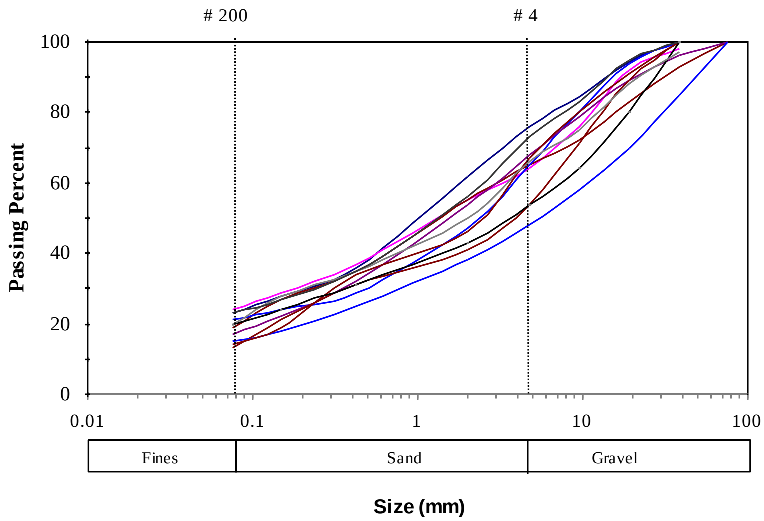

Figure 1: Some samples of Asalooye soil gradation

Considering the dimensions of used mold (25*50*50), the soil gradation was modified in a way that according to ASTM recommendation the largest diameter of used grain in soil sample, constituted 20% of smallest mold dimension. In other words, grains with diameter larger than 2 inches were excluded from soil gradation and they were replaced with grains with the size of fine gravel. Finally basic soil gradation curve was obtained which can be seen in Figure (2). Physical characteristics of basic soil have been presented in table (1).

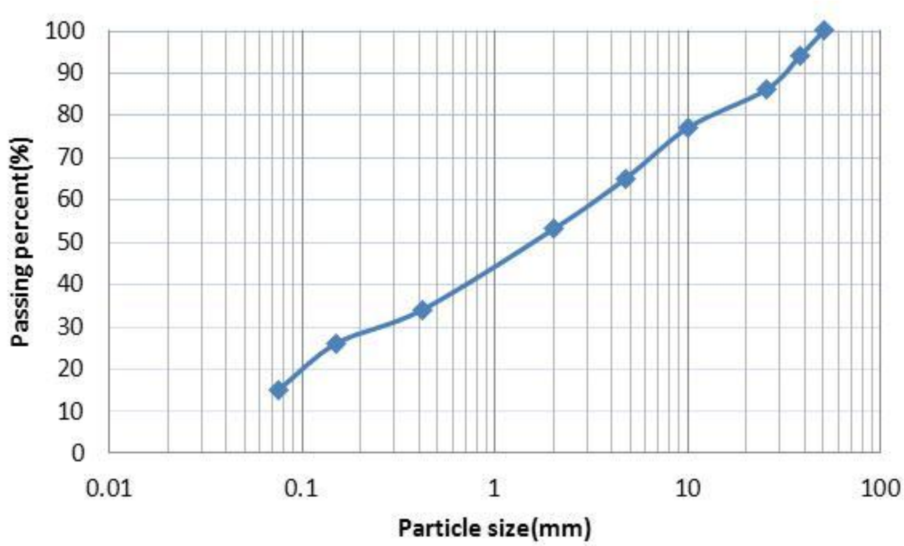

Figure 2: Gradation Curve of Used Basic Soil

Table 1: Physical characteristics of the Basic Soil

Index	**Amount**
Percent of fine materials(%)	15
Percent of sand(%)	50%
Percent of gravel(%)	35%
Minimum density(gr/cm^3)	2.07%
Maximum density(gr/cm^3)	2.22
Classification	SM
Specific Density	2.71

Preparation of Samples
All considered samples which were used to study the effect of dynamic compaction were provided form determined basic soil. The soil moisture content was considered 5% which is equal to moisture content of embankment materials of land reclamation project in Asalooye. A cubic mold with dimensions (50×50×25 cm) was used for samples compactions and preparation.
In some samples lower parts of them were saturated to investigate effects of underground water on tamping method and soil improvement rate.
Dynamic Compaction Method of Samples
Sample stamping and compaction operations were carried out, after preparing samples. The energy applied on embankment mass in lands reclaimed in Asalooye is about 25-40 tones per each cubic meter. This means that the energy rate transferred by tamper to the soil surface which equals tamper weight multiplied to height of fall, is 24 to 40 tons of meter per each cubic meter of the soil. Hence dynamic compaction of samples was carried out using 3 different energy grades similar to project site. Tamping pattern characteristics used in the laboratory have been presented in table (2).

Table 2: Tamping patterns used in the laboratory

Pattern No	**Tamper weight(kg)**	**Height of fall(m)**	**Number of tamping**	**Energy(t.m/m^3)**
P1	10	2	12	30
P2	10	2	13	35
P3	10	2	14	40

A 10kg tamper was released from 2m to tamp samples. The order of tamping to carry out dynamic compaction can be seen in Figures (3, 4). The tamps were applied on the center of the mold in 2 cases. The aim of preparing these samples is to investigate compaction below tamping point.

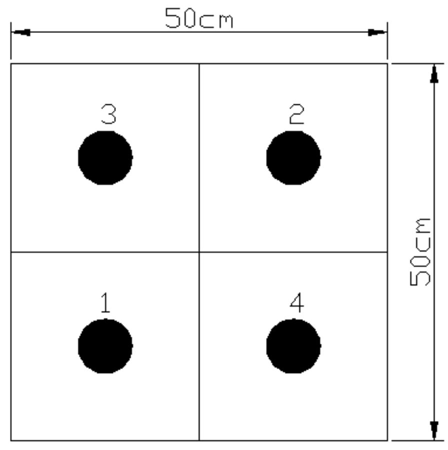

Figure 3: Tamping order of Samples

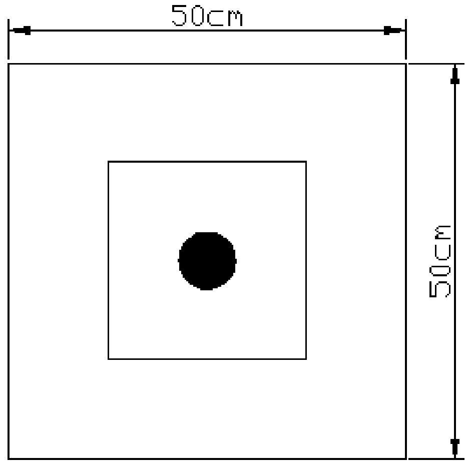

Figure 4: Tamping condition of some samples

An image of a sample and tamping operations can be seen in Figure (5).

Figure 5: Tamping and Dynamic compaction of samples

Table (3) shows characteristics of remolded samples and used patterns in their tamping.

Table 3: Characteristics of compacted samples

Sample No.	Pattern of tamping	Water content(%)	$\gamma_d\,(\frac{gr}{cm^3})$
S1	P1	5	2.07
S2	P1	5	2.11
S4	P2	5	2.18
S5	P2	5	2.16
S6	P2	5	2.18
S7	P3	5	2.22
S8	P3	5	2.19
S9	P3	5	2.2
S10	P3	5	2.09
S11	P3	5	2.1
S3	P1	*Saturated*	---

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Samples Test

Plate load and density tests were used to investigate dynamic compaction.

A plate with 10cm of diameter was used to do load tests and an accurate hydraulic jack was used for load provision. When loading, it was tried to make the pressure steps similar to plate loading tests carried out at project site. After applying normal pressure, the settlements were recorded for each step when settlement differences in 5 minutes was less than 0.01 mm. Figure (6) shows test method of plate loading. Considering that, the plate loading test in project site was carried out on a plate with 45cm diameter to reach pressure surface to18kg/cm^2, it was also tried in laboratory to continue plate loading test to mentioned pressure.

Mold dimensions and measurement of average thickness of the sample after compaction, were used to determine density.

Figure 6: Plate load test apparatus

Issues about Plate Load Test and Deformation Modules

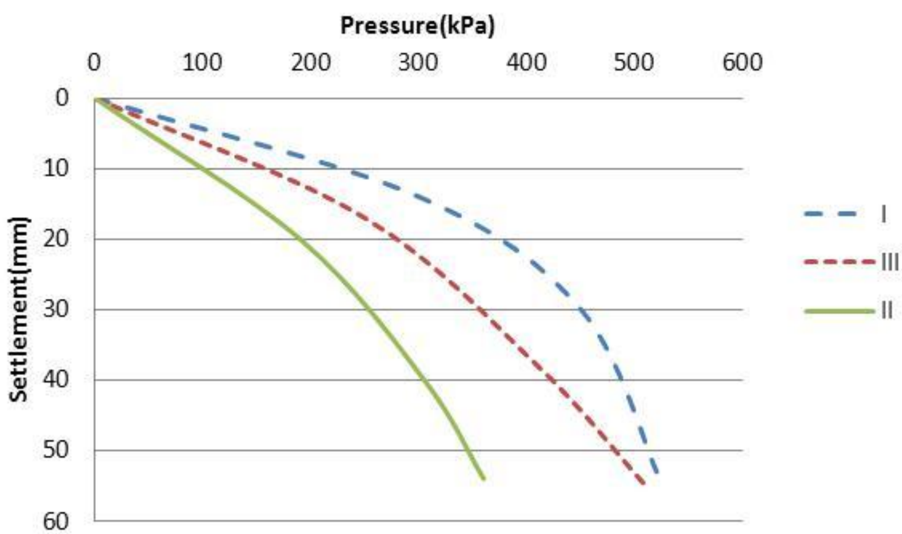

Figure 7: Pressure-settlement curves in plate load tests

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Based on soil strength, Pressure-settlement curve of plate load tests is usually as one of conditions shown in Figure (7).
Settlement-pressure curves of our tests on compacted samples are as conditions I and III. Studied parameters of plate loading test, include subgrade reaction modulus (K_s) and deformation modulus (E_s).
Subgrade Reaction Modulus
This parameter is defined as follow:

$$k_s = \frac{\Delta P}{\Delta S}$$

Where ΔP is pressure variation and ΔS is settlement variations.
Various methods have been proposed for estimation of $k_{s.}$ Terzaghi (1955) considered k_s in half of ultimate strength part of settlement-pressure curve. Al-sanad *et al.*, (1993) and Ismael (1996) chose slope of mentioned curve line to calculate $k_{s.}$ Considering factor of safety 3 for design, Lin *et al.*, (1998), determined K_s at 1/3 of ultimate strength.
Since settlement-pressure curves of conducted tests have determined linear part, and there is no failure in some tests, so the slope of linear part of the curve is appropriate for k_s determination and k_s of all tests in plate load tests were determined in this method.
Considering the similarity loading steps in the project site and laboratory, it seems necessary to establish a relationship between recorded settlements in the laboratory and Asalooye project site.
Using results of plate load tests, Terzaghi (1995) presented following relation to calculate subgrade reaction modulus for foundations on granular soils:

$$k_s = k_1 \frac{(B + B_1)^2}{4B^2}$$

Where B_1 is diameter of plate used in load test and B is width of underlying foundation and k_1 is subgrade reaction modulus obtained from plate load test.
Deformation Modulus
Another parameter which can be obtained based on plate load test and elasticity theory, is deformation modulus or soil elastic modulus E_s which is calculated using following equation:

$$E_s = \frac{\Delta P}{\Delta s} D(1 - \nu^2) I$$

Where ΔP is pressure variations, D is plate diameter, ν is poisson's ratio, I is influence factor which is a function of rigidness and load plate shape. ΔS indicates settlement rate. I-value is 0.786 for circular and rigid plates on semi-infinite elastic and homogeneous space (Timoshenko and Goodier, 1970).
Tests Results

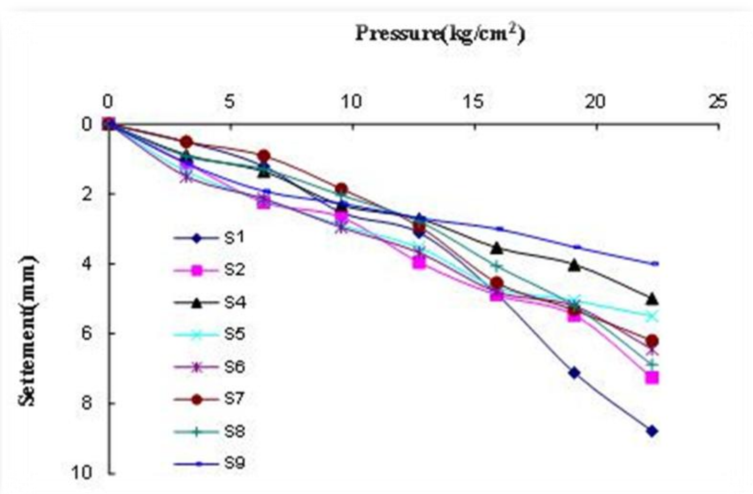

Figure 8: Plate load test curves in laboratory (for a plate of 10 cm diameter)

After performing plate load tests and obtaining soil reaction modulusfor a plate with 10cm of diameter, modulus value of subgrade reaction was calculated for a plate 45 cm of diameter, then settlement values in the laboratory were converted to settlement values at project site. Doing so, the modified curve was drawn and K_s values were obtained. Figures (8, 9) show plate load test curves and converted curves, respectively.

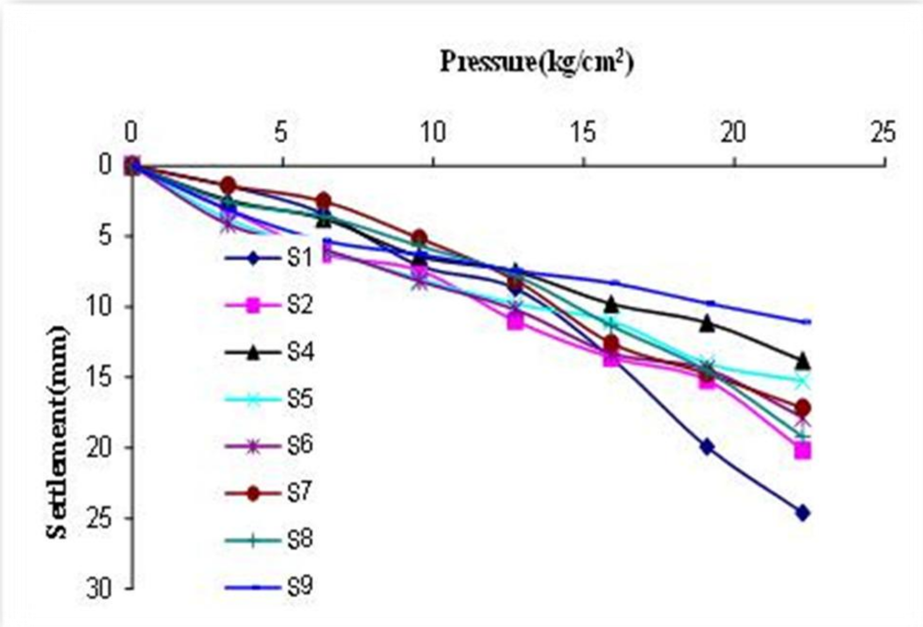

Figure 9: Converted plate load test curves (for a plate of 45 cm diameter)

One of the samples (sample 3) has been tested in a saturated condition. The aim of this test was to investigate the effects of moisture content of the sample onthe reaction modulus and the bearing capacity of the soil. The settlement-pressure curve of mentioned sample has been shown in figure (10). The characteristics of conducted tests are illustrated in table (4) as well.

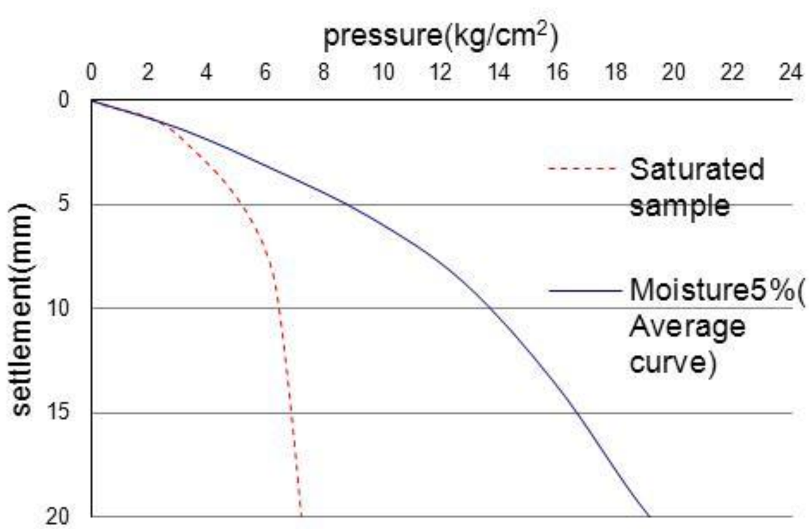

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Figure 10: Comparison of pressure- settlement curvesfor a sample with natural water content and a saturated sample

Table 4: Plate load tests results on compacted samples

Sample No.	Tamping Patt.	$\gamma_d\left({}^{gr}\!/_{cm^3}\right)$	$k_{s(45)}$ (kg/cm^3)	E (kg/cm^2)
S1	P1	2.07	12	450
S2	P1	2.11	14	499
S3	P1	2.09	5	178
S4	P2	2.18	17	630
S5	P2	2.16	14	559
S6	P2	2.18	15	570
S7	P3	2.22	22	844
S8	P3	2.19	30	1119
S9	P3	2.20	27	976
S10	P1	2.09	13	486
S11	P3	2.10	15	649

Results Analysis

Results of tests obtained for compacted samples in the laboratory indicated that compaction rate has direct relationship with tamping energy, in a way that with increase of energy, improvement rate increases accordingly. Using patterns P2 and P3, values of deformation modulus and soil subgrade reaction modulus increased 20% and 50%respectively, for plate with diameter 45 cm to compacted soil with pattern P1.Study of dynamic compaction in the laboratory indicated that plate subgrade reaction modulus with diameter 45cm increased more than 12 kg per each cubic centimeter. This is while values measured at Asalooye site for fill material was about 4-6 kg per each cubic centimeter. This shows 240% increase of these parameters after tamping samples in the laboratory. Deformation modulus for underlying plate reached more than 450kg per square centimeter. This shows an increase of 160% compared to values before tamping in Asalooye site. As soil was saturated, the strength rate of samples compacted in the laboratory decreased considerably.The average rate of such reduction was about 60%. Moreover investigation of samples dry density indicated relative increase of samples densitywith increase of compaction energy. These increased values are 4% and 5.5% for P2 and P3 patterns compared to P1 pattern.

Studying results obtained from project site and the laboratory indicated good balance of the results. As an example, results obtained in the field and laboratory has been compared in Figures (11, 12).

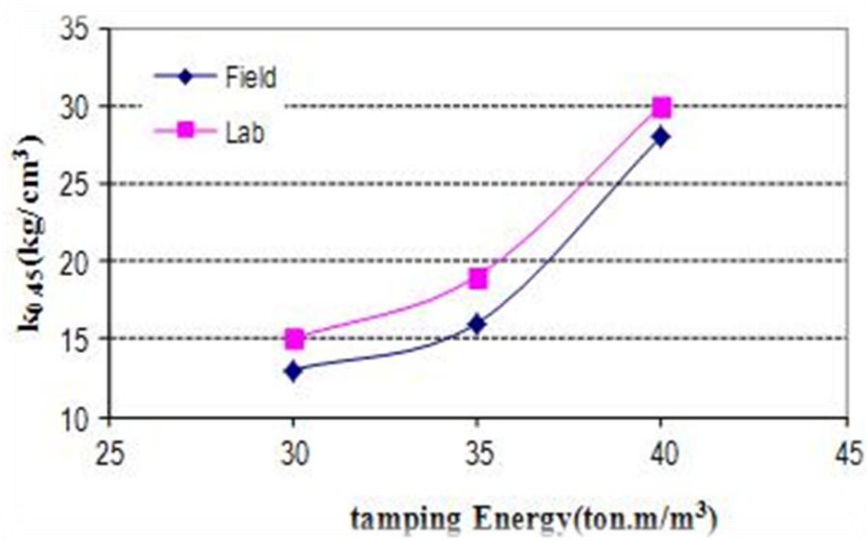

Figure 11: Comparison of subgrade reaction modulus in project site and the laboratory

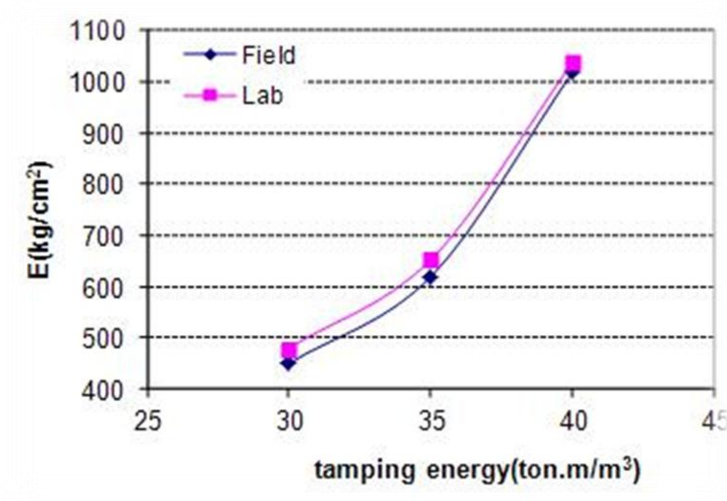

Figure 12: Comparison of deformation modulus estimated in the project site and the laboratory

As it can be seen in figures (11, 12) k_s and E values in the laboratory are more than field. Subgrade reaction modulusvalues for different energieswere 20% more than field, normally. The average increase of deformation modulus values in energies 30-40 tons meter per cubic meterwas estimated 6% more than values measured in the field. This increase is caused by confining of physical model used in the laboratory due to small dimensions of the model.

Conclusion

Dynamic compaction method is used to improve lands reclaimed from the sea at energy area of Pars (Asalooye). Most similarities and accordance were observed with comparison of dynamic compaction results obtained for laboratory and project site. According to the results of this study it was observed that with increase of compaction energy, soil improvement rate increases accordingly. So it seems that use of dynamic compaction method for soil improvement is more efficient in similar projects. Among the difficulties of dynamic compaction operations in these projects are soil layers saturation due to increased pore water pressure and increasing level of ground waters. Some solutions should be found for this phenomenon. Studying results obtained in the laboratory and relative comparison of them with parameters measured in the field, these results can be used as appropriate criteria for primary evaluations of energies use for dynamic compaction in the field.

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