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Efficiency of Improvement Techniques for Moderate Thickness Weak Soil Layers in Port Said

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ABSTRACT

Engineers may replace weak soil that extends to a relatively large thickness or use a deep foundations solution. These solutions may be expensive and sometimes have difficulties in implementation on-site. The other alternative solution is to improve the soil properties. In this paper, several methods for soil improvement were experimentally studied. Partial soil replacement of weak soil by replacing 10% to 30% of its thickness, dynamic compaction using different impact energies, and dynamic replacement with different dynamic replacement depths were studied. Comprehensive laboratory tests were performed on a soil profile model constructed in a square wooden box of 1.60 x 1.60 m and a depth of 1.20m. The tested soil profile consisted of 60 cm sand and the top layer of 40 cm weak soil imported from a construction site in Port Said city. Kinetic compaction energy was calculated for both laboratory and in-situ conditions. The effectiveness of each improvement method was demonstrated and discussed. Finally, recommendations to guide geotechnical engineers in selecting a suitable method for improving such soil types were concluded.

Keywords: Weak soil, Soil improvement, Dynamic compaction, Dynamic replacement, Soil replacement, Impact energy, Improvement guidelines

1. INTRODUCTION

Weak soil may be unable to bear loads due to excessive settlement. Weak soil can be a superficial layer extending to small depths or a layer extending to deep distances. Improving soil properties to reduce foundation problems is a challenge for many engineers [1, 2], as there are many types of weak soils, such as silty sand and clay soils. There are many methods used to improve soil properties studied in the literature [3-7]. Jahangiri et al. [8] studied the modeling of the tamper on the soil surface by applying the initial velocity to the tamper elements to consider the compression yield and the plastic stiffness of the soil under impact loads. The research proposed an approach to find the required print spacing using two series of design curves to achieve the required degree of pressure at a given depth in dry sandy soil or saturated sand under drained conditions.

Al-Adhadh et al. [9] and Atta et al. [10] studied some techniques that improve soft clay soil, including removing and replacing soil, Their research studied the improvement of clay soil, taking into account the properties of the soil, including shear strength, bearing capacity, and settlement. The effect of lateral dynamic compaction on a slope of dry sand was carried out with a typical laboratory test by Abdizadeh et al. [11], while Chong Zhou et al. [12] carried out a numerical investigation using three-dimensional finite elements. The feasibility of their model was supported by comparison with centrifuge model results. They concluded that the decrease in energy and drop momentum plays a major role in the impact, whereas the effect of drop number and tamper radius is relatively smaller. There is saturated drop energy, after which the application of more energy has little effect on soil improvement, and low drop with heavy tamper has a great effect in improving a large area of the soil and a greater depth of improvement, which is more suitable for improving the soil between the points of impact.

Khaled et al. [13] conducted experimental measurements supported by numerical model results based on a model of plasticity by Mohr-Coulomb and the finite element analysis to investigate the structural behavior of soil under the influence of loading using the Rapid Impact Compaction. A finite element code was developed for modeling the impact behavior of dry and moist granular soils by Ghassemi et al. [14]. The developed code was able to simulate the dynamic compaction treatment in dry and moist soils. Arslan et al. [15] studied the effect of the shape of the tamper on the dynamic compaction, which led to improving the efficiency and decreasing the cost of deep compaction. Another research was conducted by Zhang et al. [16]. They performed laboratory experiments and used an analysis system to record and analyze dynamic compaction test results. They used the results obtained from tests to determine the efficiency of dynamic compaction in dry areas with low water levels and determined the energy level that could compensate for the poor effect of dynamic compaction caused by low water content in dry regions. A method developed based on impact engineering formulation, taking into consideration drop height and pounder weight and shape to predict the deformation modulus that would be achieved for a certain penetration depth was studied by Merwe and Purchase [17].

Dynamic Replacement (DR) is a ground improvement technique used for treating soft compressible cohesive soils [18]. It has been used in numerous land projects and many offshore works with seabed as deep as 15 m below sea level. The concept of the subject is to explore the possibility of performing dynamic replacement at water depths almost double the previous works and to verify the achievements and estimate the soil parameters using the Menard pressure meter test (PMT) [19]. The influence of the column formation assessed with piezocone and dilatometer measurements, as well as by changes in the strength and deformation parameters were obtained from the field tests by Sekowski et al. [20]. They concluded that the changes occurring in the soil surrounding a DR column are complex, it depends on the distance from the column, elapsed time, the type, and the initial condition of the soil.

After reviewing the literature, it was noted that there is a lack of research on improving relatively thick layers of weak soil. Additionally, there is no information available on selecting the appropriate method based on the required degree of improvement. This experimental study aims to address this gap by using scaled laboratory models. The research is significant as it will provide geotechnical engineers with a simple and effective way to choose the suitable method for soil improvement based on the required degree of soil stiffness enhancement.

2. EXPERIMENTAL WORK

2.1. Laboratory Model

The Port-Said area has a typical soil profile in most areas. This profile consists of 1 to 3 meters of fill in the top layer followed by a sand layer that extends to 12 meters in most cases. The underneath layer consists of soft clay, which is 50 meters deep in most locations. In some areas in Port Said, the top layer may be silty sand or sandy silt with a thickness of 6 to 10 meters, [21]. The soil extracted from the south Port-Fouad/east Port-Said area, that forms this moderately thick top layer, is laboratory tested to find its mechanical properties before proceeding with soil improvement methods. A laboratory model was created for saturated weak soil imported from a construction site in the Port Said industrial zone consisting of silty soil. Tests were conducted on the soil profile represented in the laboratory model. The experimental program aims to improve the properties of weak soil of medium thickness (5-10) m. A laboratory model has been constructed from layers of soil according to the control of study areas, as shown in Figure 1, and Figures 6 to 8.

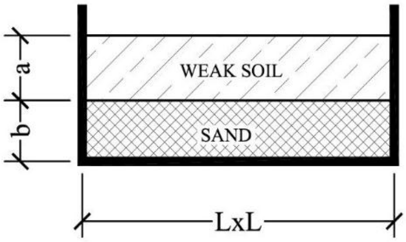


Figure 1: Layout of container and dimension notations

The model dimensions were $L = 1.60$ m, $b = 0.6$ m, and $a = 0.4$ m. These dimensions were chosen to simulate the weak soil layer thickness to scale 1:20, this scale is chosen to be suitable for this type of moderate thickness weak layers, laboratory model manufacturing, instrumentation, and handling of loads. The 40 cm weak soil layer represents 8 m thickness in field conditions. The plan dimensions of the box were chosen such that the effects of soil extensions beyond footing edges were eliminated. The scaling ratio was used for structure footing and other parameters. The experimental program consists of three groups. Each group studies a soil improvement technique. For each test, settlements versus loads were recorded. Two footing sizes were used, the footing dimensions were 10x10cm^2 (F1) and 20x20 cm^2 (F2). All footings are made from steel plates of 10 mm thickness ensuring rigid footing to distribute contact stresses on soil uniformly. The square footings were connected to a vertical steel column and ended with a loading table to apply loads upon the footing system.

2.2. Soil Tests and Classification

Tests were carried out on the compacted bottom sand layer. Sieve analysis, compaction, specific gravity, and unit weight tests were performed. Also, a direct shear test was performed to determine the angle of internal friction. As for the silty soil layer, Sieve analysis and hydrometer tests were conducted to determine the diameter of the grains. Furthermore, the Liquid limit, plasticity limit, and consolidation test were performed to classify the soil. Also, a direct shear test was conducted to determine the cohesion and the angle of internal friction. Figure 2 and Table 1 summarize the test results of the sand layer and weak soil.

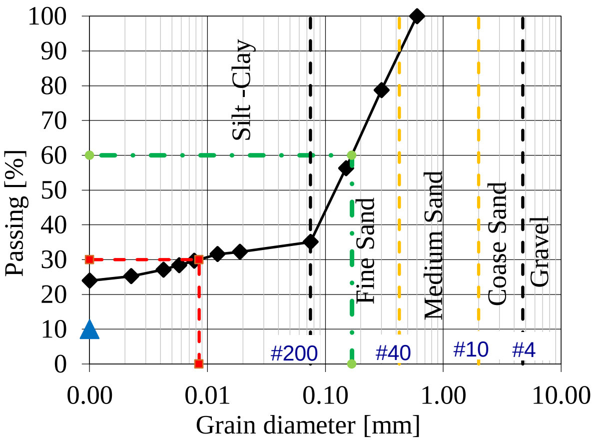


Figure 2: Sieve analysis of weak soil sample

Table 1: Properties of soil layers

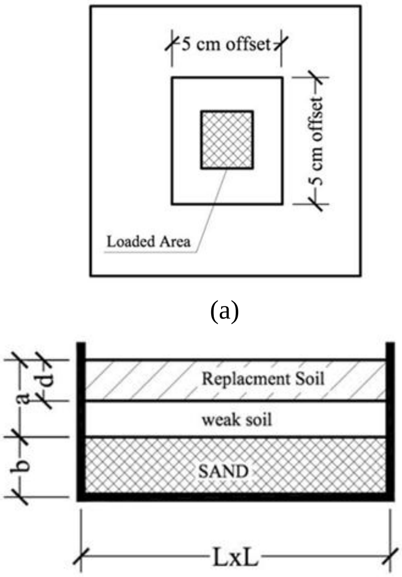
Sand Layer and Soil of Replacement		
Specific gravity	Unit weight kN/m^3	Angle of Internal Friction
2.69	17.4	35^o
Weak Soil Layer		
Liquid Limit L.L.	Plastic Limit P.L.	Plasticity Index P.I.
64%	39%	25%
Cohesion C kN/m^2		30
Angle of internal friction		15^o
Soil classification		Silty sand

2.3. Group of Soil Replacement Method

In this group the Soil Replacement (SR) improvement technique was studied, Figure (3) describes the method of performing soil replacement while Table 2 summarizes the study parameters.

Table 2: Soil Replacement study parameters

Test	Replace-ment Soil	Lab. Depth d [cm]	Footing Size	in-situ depth [m]
SR 1 F1	Sandy soil	5	F1	1
SR 2 F1	Sandy soil	10	F1	2
SR 3 F1	Sandy soil	15	F1	3
SR 1 F2	Sandy soil	5	F2	1
SR 2 F2	Sandy soil	10	F2	2
SR 3 F2	Sandy soil	15	F3	3



(a)

(b)

Figure 3: Replacement method details and its projection from footing: (a) plan, (b) section

2.4. Group of Dynamic Compaction Method

The Dynamic Compaction (DC) soil improvement technique was studied in this group. Table 3 summarizes the study parameters while Figures 4,10, and 11 describe the procedure of the dynamic compaction process:

Table 3: Dynamic Compaction (DC) study parameters

Test	Energy [W x h]	Footing
DC 2.5 H15 F1	2.5 kg x 15 cm	10 x 10 cm^2
DC 2.5 H30 F1	2.5 kg x 30 cm	10 x 10 cm^2
DC 2.5 H45 F1	2.5 kg x 45cm	10 x 10 cm^2
DC 5 H15 F1	5.0 kg x 15 cm	10 x 10 cm^2
DC 5 H30 F1	5.0 kg x 30 cm	10 x 10 cm^2
DC 5 H45 F1	5.0 kg x 45cm	10 x 10 cm^2
DC 7.5 H15 F1	7.5 kg x 15 cm	10 x 10 cm^2
DC 7.5 H30 F1	7.5 kg x 30 cm	10 x 10 cm^2
DC 7.5 H45 F1	7.5 kg x 45 cm	10 x 10 cm^2
DC 5 H45 F2	5.0 kg x 45 cm	20 x 20 cm^2

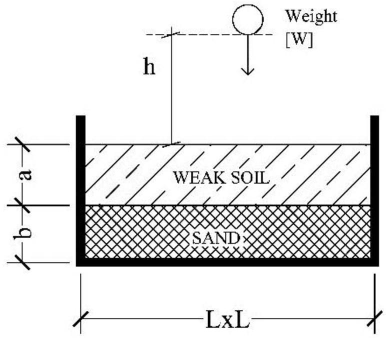


Figure 4: Dynamic compaction notations

2.5. Group of Dynamic Replacement Method

In this group, the Dynamic Replacement (DR) soil improvement technique was studied as shown in Figures 5 and 12. Table 4 summarizes the study parameters. The models were loaded by 20x20 cm footing size only.

Table 4: Dynamic replacement study parameters

Test	Replacement Soil	Height [cm]	Load [kg]	Equivalent Replacement depth c [cm]	In-Situ depth [m]
DR 0.5	Sandy soil	45	5.0	2.5	0.5
DR 1	Sandy soil	45	5.0	5	1.0
DR 1.5	Sandy soil	45	5.0	7.5	1.5

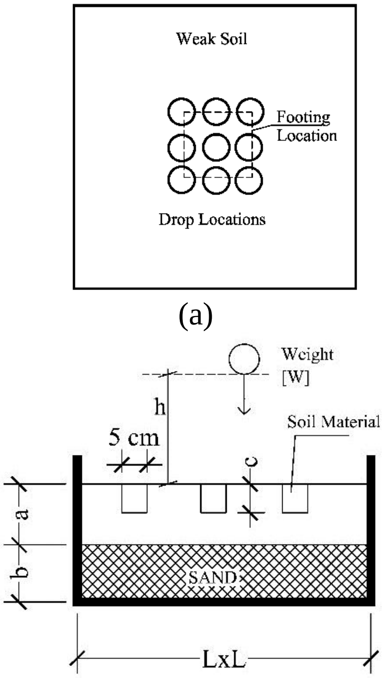


Figure 5: Dynamic replacement notations (a) Plan, (b) Section

2.6. Test Setup

After each improvement technique was conducted on the laboratory soil profile, a static loading was applied gradually on footing resting on the soil. A dial gauge is mounted to measure settlement after each loading increment, see Figure 8. The settlement of each loading increment is recorded after 24 hours or when the settlement changes are negligible.

Figure 6: Thin film coating for waterproofing

Figure 7: Adding a bottom layer of sand.

Figure 8: Final stage of scaled soil profile and test setup

Figure 9: Preparation of partial replacement under footing

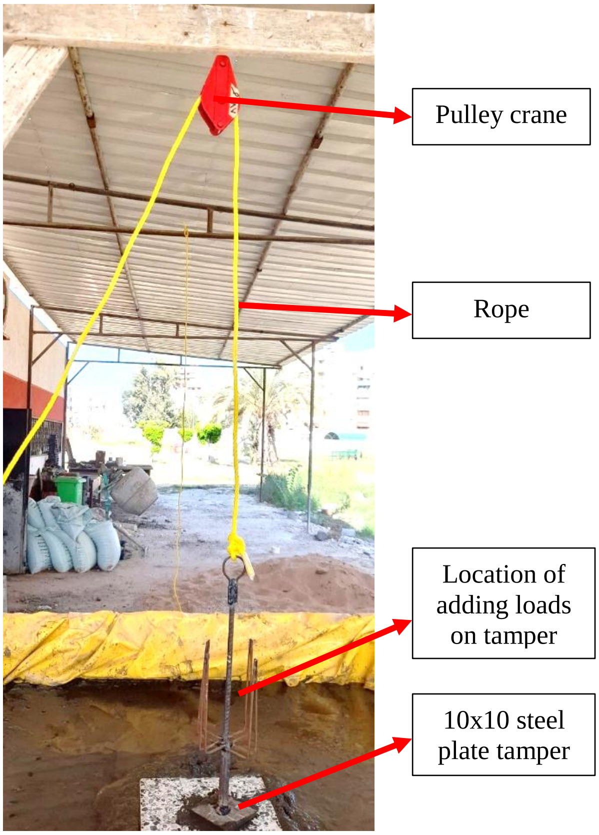


Figure 10: Dynamic compaction mechanism

Figure 11: Weak layer surface after application of dynamic compaction

Figure 12: Weak layer surface after application of dynamic replacement with sand

3. RESULTS AND DISCUSSION

3.1. Soil Replacement Method

In this method of soil improvement, the replacement was made with graded sand using three different scaled depths: 5 cm, 10 cm, and 15 cm on both footing sizes. It should be mentioned that the scaled replacement depths correspond to 1m, 2m, and 3 m in actual field depths, respectively. The sand layer was placed and compacted in layers to reach the optimum field density.

3.1.1. Effect of different replacement depths for small footing size

As shown in Figure 13, the effect of increasing soil replacement thickness on settlement is significant. When increasing its thickness, the soil stiffness, as well as its bearing capacity, is increased. However, a further increase of SR thickness than twice the footing size will not be useful. The results also showed that increasing replacement thickness more than footing size will lead to a small increase in soil stiffness and bearing capacity. In addition, the increase in stiffness appears in higher levels of loading than in the first loading stages. Figure 14 shows the footing settlement and the shape of the surrounding soil after loading.

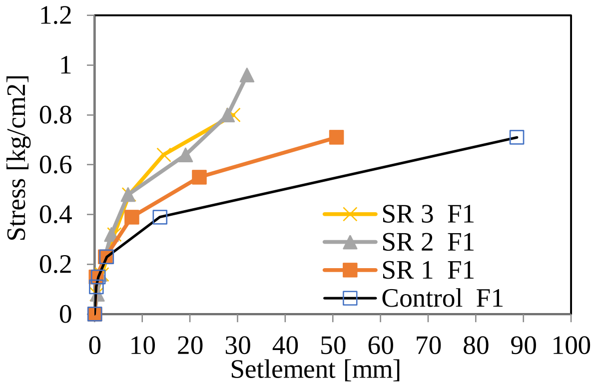


Figure 13: Stress-settlement curves for control soil and different replacement thicknesses 5, 10, and 15 cm for F1

Figure 14: Settlement under footing for SR method

3.1.2. Effect of different replacement depths for big footings size

As shown in Figure 15, the effect of increasing replacement thickness on settlement is significant. When increasing replacement thickness, the soil stiffness, as well as its bearing capacity, is increased. The effect of soil replacement is significant when it is near footing size. It can be noticed that for SR of 5 and 10 cm, the increase in soil stiffness is less than in SR of 15cm. In addition, the response of stress-settlement relationships seems to have a linear response than for 10x10 cm footing.

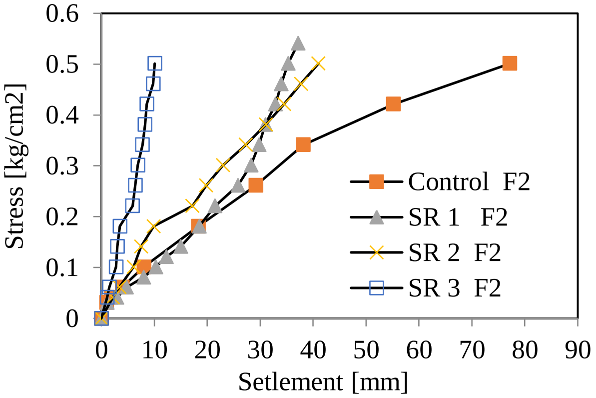


Figure 15: Comparison stress-settlement curve for footing 20x20 cm^2 for control soil and different soil replacement thicknesses

3.2. Dynamic Compaction Method

In this method of soil improvement, dynamic compactions were performed with the aid of falling loads from specified heights. These loads were 2.5, 5, and 7.5 kg falling from three different heights 15, 30, and 45 cm. Nine trials were performed, and the load settlement performance was measured for footings size 10x10 cm^2. Taking the best combination of load and falling height obtained from the previous nine trials, only one weight value of 5 kg falling from 45 cm was used to investigate load settlement for footing size 20x20 cm^2. For each load and falling height in each trial, a fixed number of drops for each plot was maintained, which was 25 drops for each trial.

Referring to Figures (16 to 18), the reader can notice that the increase in drop height will lead to an increase in soil stiffness. It was noticed that there is no remarkable difference between different values of impact load falling from a height of 45 cm. which indicates that a height of 45 cm is the most effective drop height. Also, there is no great difference in the effect for loads 5 kg and 7.5 kg falling from a height of 45 cm. From all drop heights and different values of impact loads, it may be concluded that using an impact load of 5 kg falling from 45 cm is the most effective impact energy to be used for such soil thickness. From the studied cases for the dynamic compaction tests and the examined silty sand layer, the weak layer's average energy per unit depth could be 5.625 kg. cm/cm. This value is considered sufficient to cause an acceptable degree of compaction of such soil.

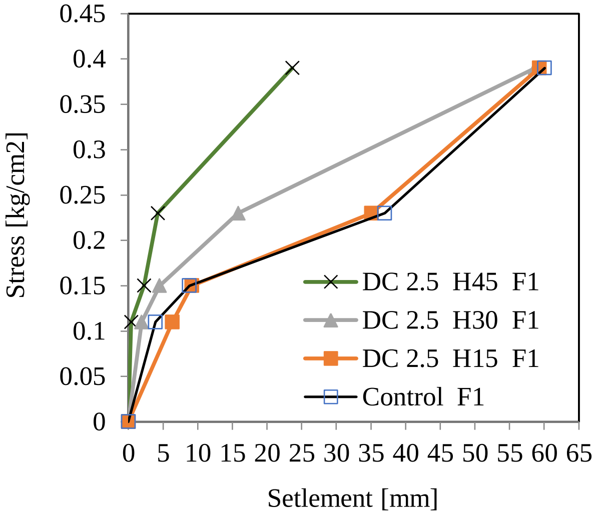


Figure 16: Stress-settlement curves for control soil and dynamic compaction by 2.5 kg for heights 15, 30, and 45 cm for F1

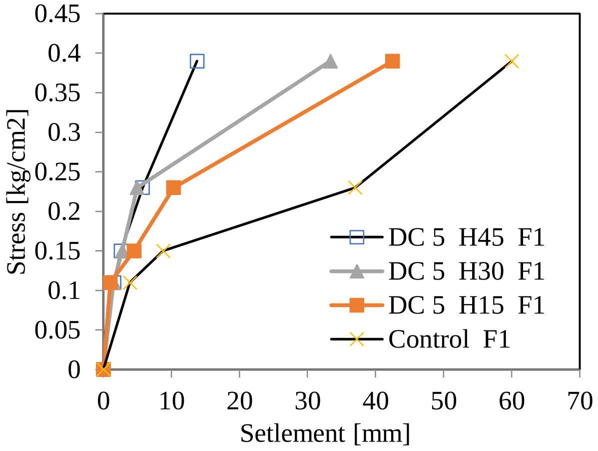


Figure 17: Stress-settlement curves for control soil and dynamic compaction by 5 kg for heights 15, 30, and 45 cm for F1

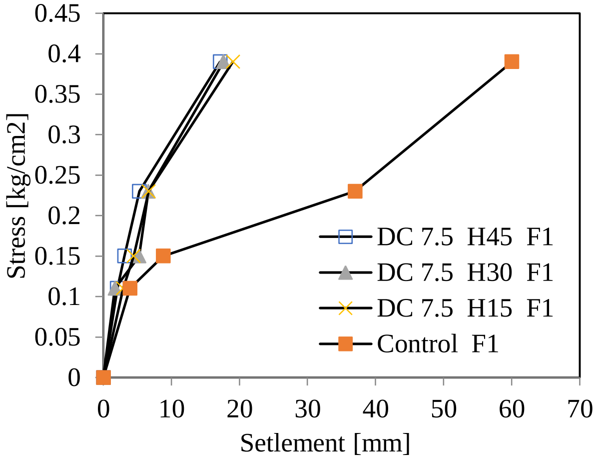


Figure 18: Stress-settlement curves for control soil and dynamic compaction by 7.5 kg for heights 15, 30, and 45 cm for F1

3.3. Dynamic Replacement Method

In this method of improvement, dynamic replacements were performed by dropping a 5 kg load falling from 45 cm height accompanied by adding a specified amount of sand. Coarse sand of a 35 angle of internal friction was used as a dynamic replacement material. Three different levels of sand insertion were chosen in the laboratory model which are 2.5, 5, and 7.5 cm. The penetrated depths were chosen to be equivalent to 0.5, 1.0, and 1.5 m in the in-situ conditions. It should be noted that a scale of 1:20 was used to transform from in-situ size to laboratory size. The penetration depth of each trial was controlled by the amount of sand. Referring to Fig. 19, adding more sand, which is compacted dynamically, will lead to an additional increase in the stiffness of the soil. The DR method of 1.0 sand equivalent depth gave a better performance for the tested soil.

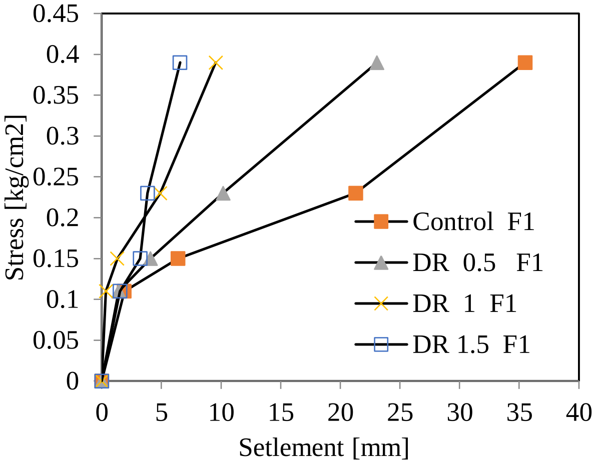


Figure 19: Stress-settlement curves for control soil and dynamic replacement by 5 kg for height 45 cm with first, second, and third trials for F1

3.4. Modulus of Subgrade Reaction

The modulus of subgrade reaction is related to soil stiffness. The secant stiffness for different improved soils was estimated at a stress of 0.3 kg/cm^2. This value of stress is taken as a reference for all tests to measure soil improvement's effect on soil modulus of subgrade reaction or soil resistance to excessive settlements. The soil stiffness is estimated by dividing the reference stress by the corresponding footing settlement. Then, the improvement factor is calculated by dividing the enhanced soil modulus by the control one, see Figure 20.

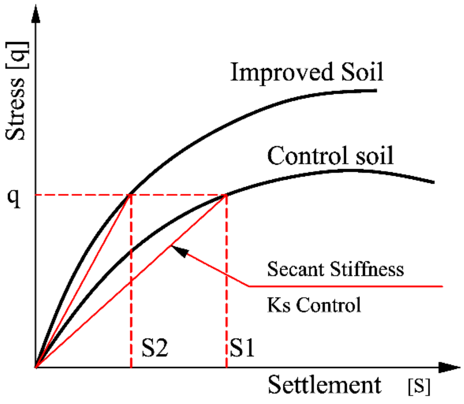


Figure 20: Determination of the improved modulus of subgrade reaction or soil stiffness

3.4.1. Soil replacement

Table 5 shows the improvement factor for the soil replacement method. Results show that improvement in footing F1 increases with replacement depth. When using 5, 10, and 15 cm replacements, the improvement ratio was 30, 100, and 160 % more than the control case, respectively. While, in larger footing F2, using 5, 10, and 15cm replacements, the improvement ratio was

22, 44, and 378 % more than the control case, respectively. The footing affects the increase of the improvement factor. The increase in soil stiffness appears clear when replacement depth reaches at least footing width, Figures 21 and 22.

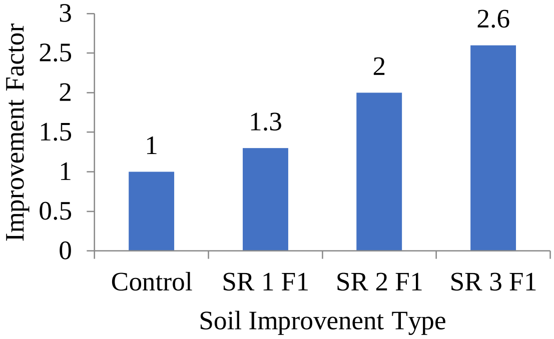


Figure 21: Improvement factor for soil replacement method for footing F1

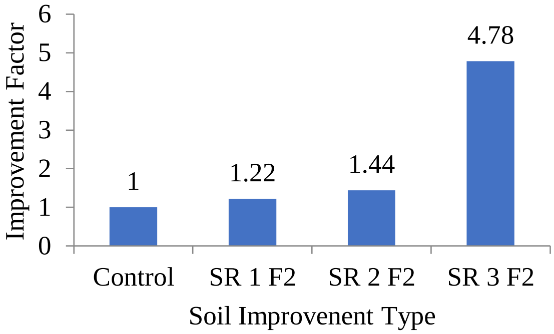


Figure 22: Improvement factor for soil replacement method for footing size F2

Table 5: Improvement factor for soil replacement method

Soil Replacement [SR] Footing F1	Control	SR - 5cm	SR-10cm	SR-15cm
Ks [kg/cm^3] calculated at 0.3 [kg/cm^2]	0.375	0.5	0.75	1.0
Improvement Factor [ξ]	--	1.3	2	2.6
Soil Replacement [SR] Footing sizeF2	Control	SR - 5cm	SR-10cm	SR-15cm
K$_s$ [kg/cm^3] calculated at 0.3 [kg/cm^2]	0.09	0.11	0.13	0.43
Improvement Factor [ξ]	--	1.22	1.44	4.78

3.4.2. Dynamic compaction method

Referring to Table 6 and Figure 23, the increase in impact energy leads to an increase in the soil improvement ratio. Using a load of 5 kg falling from 45 cm (for the laboratory model) gives the optimum improvement ratio. The same effect of using 5 kg and 7.5 kg dropping from 45 cm was found. The optimum impact energy is related to the size of the footing. The affected depth of soil depends on impact energy. When using a load of 5 kg at 45 cm for a larger footing size, the increased soil stiffness was only 23 %. This limited increase in stiffness is due to the larger required depth of improvement to be compatible with footing size.

3.4.3. Dynamic replacement method

Table 7 shows improvement ratios of modulus of subgrade reaction for the dynamic replacement method. The soil is improved greatly with a small amount of replacement. The results also show that increasing the amount of dynamic replacement increases the improvement ratio. In the third case of the 7.5cm DR method, the increased soil modulus is less than it in 5cm DR. This could be referred to the effect of properties of soil as for each trial the soil is reconstructed, and this reformation will change to somehow soil properties than the reference soil, Figure 24.

Table 6: Improvement factor for dynamic compaction method

Dynamic Compaction Footing F1	**Control**	**DC 2.5H15**	**DC 2.5H30**	**DC 2.5H45**
Ks [kg/cm^3] calculated at 0.3 [kg/cm^2]	0.06	0.07	0.09	0.23
Improvement Factor [ξ]	---	1.2	1.5	3.8
Dynamic Compaction Footing F1	**Control**	**DC 5.0H15**	**DC 5.0H30**	**DC 5.0H45**
Ks [kg/cm^3] calculated at 0.3 [kg/cm^2]	0.06	0.12	0.17	0.33
Improvement Factor [ξ]	---	2.0	2.83	5.50
Dynamic Compaction Footing F1	**Control**	**DC 7.5H15**	**DC 7.5H30**	**DC 7.5H45**
Ks [kg/cm^3] calculated at 0.3 [kg/cm^2]	0.06	0.25	0.27	0.30
Improvement Factor [ξ]	---	4.17	4.5	5.0
Dynamic Compaction Footing sizeF2	**Control**	-	--	**DC 5.0H45**
Ks [kg/cm^3] calculated at 0.3 [kg/cm^2]	0.057	-	-	0.07
Improvement Factor [ξ]	---	--	--	1.23

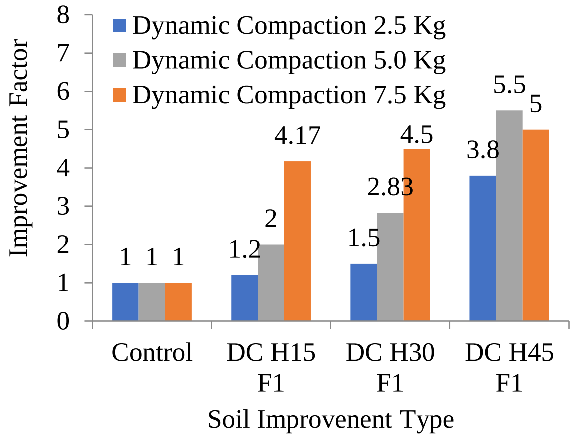


Figure 23: Comparison between different methods of dynamic compaction method

Table 7: Improvement factor for dynamic replacement method

Dynamic Replacement [DR]	**Control**	**DR – 2.5cm**	**DR-5cm**	**DR-7.5cm**
Ks [kg/cm^3] calculated at 0.3 kg/cm^2]	0.11	0.188	0.6	0.43
Improvement Factor [ξ]	--	1.71	5.46	3.91

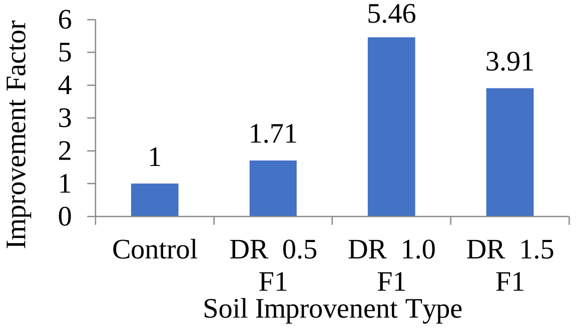


Figure 24: Improvement factor for dynamic replacement method for footing F1

3.4.4. Comparison between DC and DR methods

Figure 25 relates dynamic compaction (DC) and dynamic replacement (DR) for the same footing size. Dynamic compaction (DC) stability when increasing impact energy appeared to be much more than dynamic replacement. Figure 25 also shows to what depth the effect of impact energy is extended. Dynamic compaction using 5kg falling from 45 cm has the same effect of improvement of DR using 1.0 m replacement.

3.4.5. Comparison Between SR and DR methods

Figure 26 shows the comparison between soil replacement (SR) and dynamic replacement (DR) for the same footing size. Dynamic replacement is much more effective than soil replacement. The usage of dynamic replacement reduced the amount of required replacement soil. Using 50% of the soil replacement amount used in ordinary replacement but using dynamic replacement leads to an improvement in efficiency much more ordinary replacement.

3.4.6. Comparison Between SR and DC methods

Figure 27 compares soil replacement (SR) and dynamic compaction (DC) for the same footing size. This comparison indicated that the effect of impact energy for each falling height extended to a higher depth than the depth of replaced soil. Using impact energy of 5 kg falling from 45 cm has twice the effect of using 15cm soil replacement.

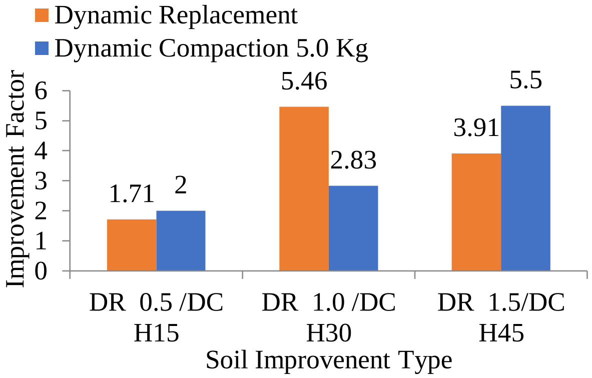


Figure 25: Comparison between dynamic replacement and dynamic compaction

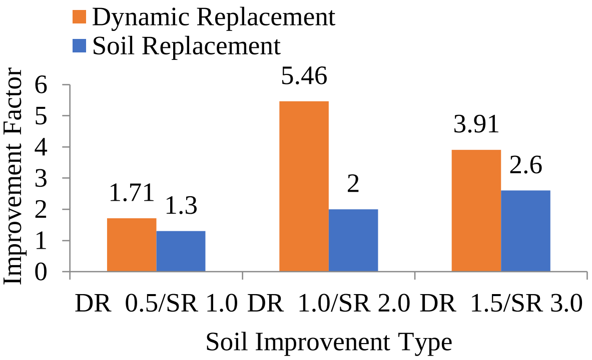


Figure 26: Comparison between dynamic replacement (DR) and soil replacement (SR)

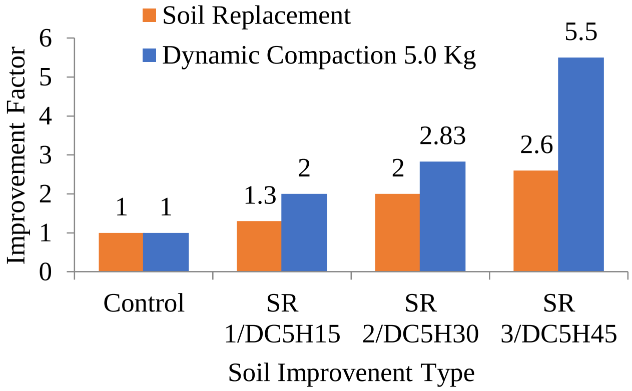


Figure 27: Comparison between dynamic compaction and soil replacement

3.5. Impact Energy Analysis

To analyze impact energy for the case of the laboratory model, a drop test is performed using the different weights and heights used in the dynamic compaction method. The penetration of each load is measured and recorded. The velocity of the impact load and the kinetic energy just before the falling object touches the soil surface are calculated, as shown in Figure 28. Table 8 shows the results of this impact test and the corresponding improvement factor extracted from the dynamic compaction test.

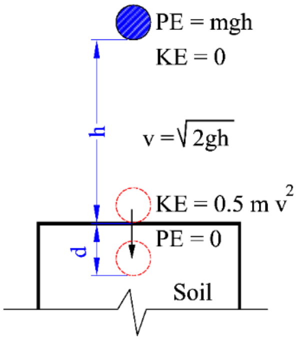


Figure 28: Analysis of falling load on deformable soil

Figure 29 shows the relation between laboratory falling height and measured penetration depth divided by falling load value. It can be noticed that there is a nearly linear relation between penetration depth and the value of falling load as the three trial curves fall over each other. This conclusion leads to the expected penetration depth in Table 9 is calculated by multiplying the laboratory-measured penetration depth by the overall scale of the model, which is 20.

Table 8: Impact energy analysis for laboratory model

W (kg)	**h [cm]**	**Measured Penetration d [cm]**	**Velocity (m/s)**	**KE [j]**	**Improvement factor**
2.5	15	1.25	1.72	0.38	1.20
2.5	30	2.23	2.43	0.75	1.50
2.5	45	3.87	2.97	1.13	3.80
5	15	2.27	1.72	0.75	2.00
5	30	3.83	2.43	1.50	2.83
5	45	7.07	2.97	2.25	5.50
7.5	15	3.97	1.72	1.13	4.17
7.5	30	6.43	2.43	2.25	4.50
7.5	45	9.50	2.97	3.38	5.00

Table 9: Impact energy analysis interpolation for in-situ condition

W (kg)	**h [cm]**	**Expected Penetration d [cm]**	**Velocity (m/s)**	**KE [j]**	**Improvement factor**
50	**300**	25	7.67	150	1.20
50	**600**	45	10.85	300	1.50
50	**900**	77	13.29	450	3.80
100	**300**	45	7.67	300	2.00
100	**600**	77	10.85	600	2.83
100	**900**	141	13.29	900	5.50
150	**300**	79	7.67	450	4.17
150	**600**	129	10.85	900	4.50
150	**900**	190	13.29	1350	5.00

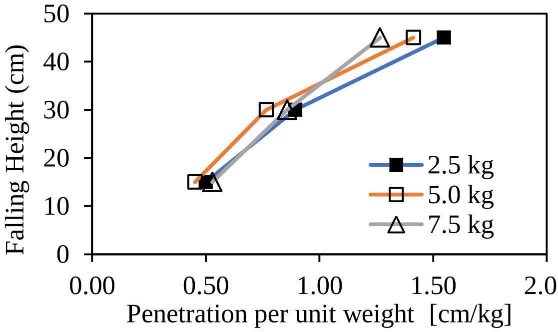


Figure 29: Relation between laboratory falling height and penetration per unit weight for dynamic compaction

3.6. Proposed In-situ Methods of Improvement

Figures 30 to 32 show the proposed methods to perform in-situ applications of soil improvement based on the required degree of stiffness improvement. The proposed method is limited to a silty sand layer thickness of about 8.0 meters as the experimental work is conducted to a layer thickness of 40 cm with a modeling scale of 20. The proposed is also limited to a small footing size of about 2 m maximum width or strip footing of 2.0

maximum width. The proposed ratios may be scaled if bigger footings are needed.

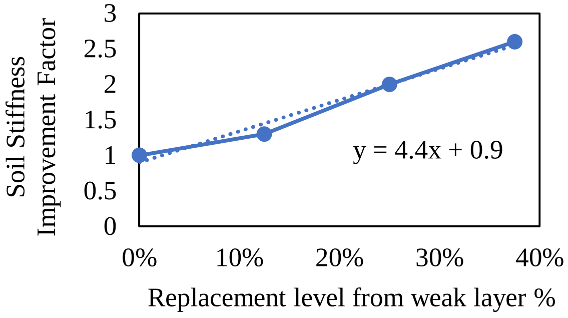


Figure 30: Relation between improvement factor and soil replacement thickness ratio for the proposed in-situ application

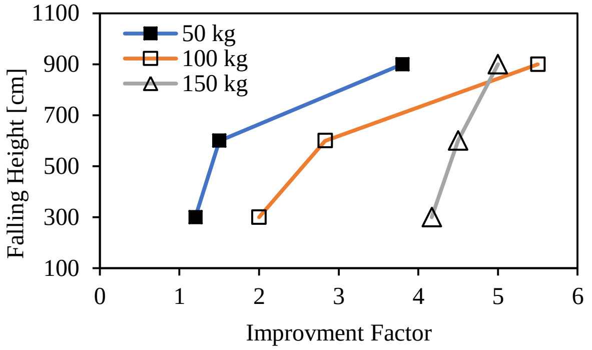


Figure 31: Relation between improvement factor and failing height with different loads for the proposed in-situ application

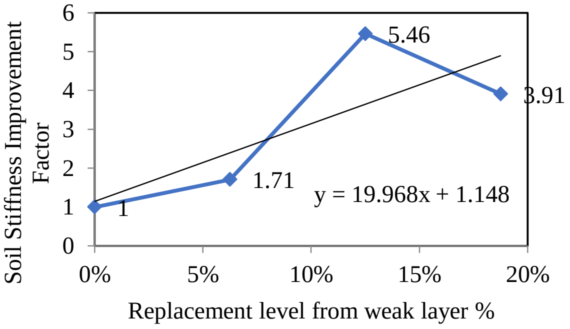


Figure 32:: Relation between improvement factor dynamic soil replacement ratio for the proposed in-situ application

4. CONCLUSIONS

Different types of soil improvement methods were investigated in this research. The response of control and improved soil was presented using stress versus settlement curves. Based on the conducted experimental study, the following could be concluded: -

- A strategy to be adopted for the in-situ applications was proposed. With the aid of this method, the geotechnical engineer can select the suitable method of soil improvement based on the desired degree of soil stiffness enhancement.
- The bearing capacity of 10x10 cm^2 footing was about 0.55 kg/cm^2, while in 20x20 cm^2 footing, it was 0.4 kg/cm^2 for the tested silty sand soil which corresponds to the 50 mm settlement limit according to ECP.
- Replacing about 40% of weak soil depth will lead to a remarkable increase in its stiffness and bearing capacity.
- Results showed that using compaction energy of 112.5 kg. cm for 40 cm of weak soil depth will lead to a good compaction.
- Dynamic replacement is more effective than ordinary replacement. Using 1.0 m equivalent dynamically replaced sand provides almost the same effect as 3.0 m ordinary replacement.

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