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Effect of Replacement Layers on Bearing Capacity of Silty Clay Layer

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Abstract**—** *Soil conditions often pose significant challenges for soil and foundation engineers engaged in construction projects. In response to these challenges, researchers and engineers have dedicated considerable efforts to developing solutions to construct on weak soil layers. The replacement layer is one of the most efficient and effective methods to increase the ultimate bearing capacity under foundation. There are many advantages for replacement layer using such as its low cost, material availability, easy construction, quick construction time, simple testing procedures. There is a few of studies that determine the actual values of the ultimate bearing capacity of replacement layers. Most research and studies focus on theoretical and mathematical values of the ultimate bearing capacity for foundations replacement layers. The site selected for this study was located in Al-Qalyubia Governorate. The use of replacement layers in this study indicated that there is an increase in the ultimate bearing capacity for the studied site. In addition to that, engineering properties of replacement layer and natural soil condition plays a role in the ultimate bearing capacity values.*

Keywords**— *Soil Conditions, Replacement Layer, Ultimate Bearing Capacity, Construction Solutions, Engineering Properties***

I. INTRODUCTION

The foundation is recognized for transmitting the structure's weight and other loads to the soil beneath it. These loads must be transmitted in such a way that the soil's capacity to hold the loads is not exceeded. To put it another way, a scientific foundation design must be based on the soil's carrying capacity [4],[12],[14] [19], and [20].

Ashraf [1], Coduto [3], Tomlinson [16], and Winterkorn [18] stated that, Layers of replacements are usually carried out with soil stronger than the original soil or at least equal to it. It is carried out in layers whose thickness does not exceed 30 cm. The main purpose to use replacement layers in the construction works as the following:

1. Rise the foundation level.
2. Increasing the bearing capacity of the soil under foundation.
3. Keeping away the structures from the area of groundwater influence or protecting foundations from ground water effects.
4. Reduce the effects of elastic soil layers such as swelling soil layers.
5. Reduce the effect of rigidity between foundation and hard soil layers such as rock soil.
6. Reduce the vertical stresses on the original soil.

As for the type of soil used in the replacement, it must be free from all the previous defects and have no relationship to the replacement soil with the original soil - meaning the replacement layer must be tested on that it is suitable for establishment [2], [4], [12], and [14].

Various types of foundations are used depending on the structure and soil encountered. Spread footing, mat foundation, pile foundation, and drilled shaft foundation are the most popular types of foundations. A spread footing is essentially an extension of a load-bearing wall or column that allows the structure's load to be distributed over a wider area of the soil. The size of the spread footings needed in low-load-bearing soil is impractically high. in that case, constructing the whole structure on a concrete pad is more cost-effective [7], [15], and [17].

Bearing capacity is the ultimate load a soil layer can support before shear failure. Settlement, on the other hand, refers to the downward movement of a structure due to soil compression under applied loads [10], and [8].

The bearing capacity calculation methods are based on theoretical considerations developed to reflect experimental observations. In case of different value of bearing capacity, using plate load test is the ideal solution to identify the more realistic value of it. In case of low bearing capacity of the soil layer, the replacement layers may be suggested to improve the bearing capacity [8], and [9].

II. THE STUDIED SITE

The site was chosen for this study where the natural soil layers is cohesive soil layers for present study purpose. the site was investigated to determine the soil classification and soil physical properties by Egyptian Military Technical Collage. **Error! Reference source not found.** shows the location of the studied site which was chosen for the experimental works. the two is located in Qalyubia Governorate, where it contains (Silty clay soil) in the land of El-Awkaf - Shubra Al-Khaima - Qalyubia Governorate - Greater Cairo. It is 200 meters from the Road Ring, and in the middle is the axis of 15 May. Soil properties of the site determined by the soil props done by the Egyptian Military Technical College, was planned for the construction of 883 social housing units. The site was planned with three building models (i) Model A: 6 floors (ground floor + 5 floors); (ii) Model B: 8 floors (ground floor + 7 floors); (iii) Model C: 10 floors (ground floor + 9 floors).

The physical and mechanical properties of the soil layers were determined to classify the soil types and soil stratifications. The engineering tests were carried out in the Soil Mechanics and Foundations Laboratory of the Faculty of Engineering, Military Technical Collage. Therefore, at the site, the Egyptian Military Technical College recommended that the excavation to a depth of 3 meters and use of replacement layers with a thickness of 1.5 meters of gravel and sand at a ratio of 1:1. So that, the replacement layers they are placed on layers of no more than 25 cm in thickness, taking into account, their immersion and compaction, using a masher of not less than 15 tons. The engineering properties of the fine soil layer at different depths are listed in Table 1 such as natural density, natural water content, specific gravity, etc. It is clear that, the index properties of natural fine soil are excessively the same values. According to unified classification system (most common used) and by using plasticity chart, it is noted that, the soil up to depth 9.0m from ground surface can be classified as CH. Where, CH represents clay of high plasticity.

Table 1: Index properties of silty clay soil

Depth (m)	**3.0**	**6.0**
Natural unit Weight of soil γ (t/m3)	1.66	1.68
Natural Water Content wc (%)	28	31
Liquid limit L.L (%)	51	53
Plastic Limit PL (%)	28	27
Plasticity index PI (%)	23	26
Shrinkage limit SL (%)	16.5	17
Specific gravity Gs	2.71	2.70
Free swell F.S. (%)	75	100
Degree of Saturation S (%)	95	100
Soil Classification	CH	CH

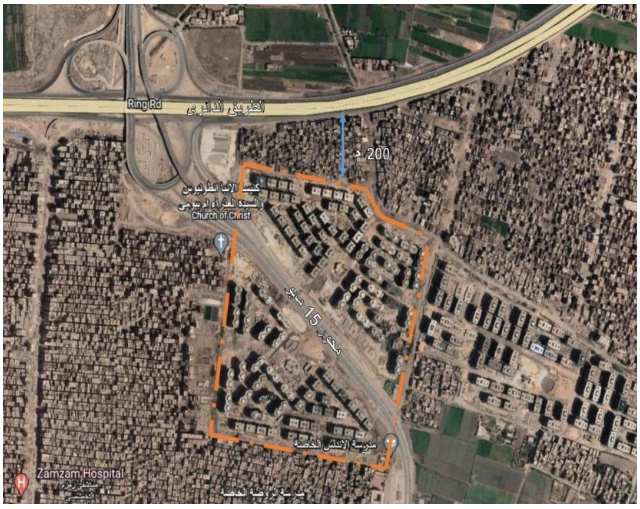

Fig. 1: Location of the site

2.1 Properties of Replacement layers

Due to the recommendation of Egyptian Military Technical Collage report to use replacement layer materials as the mixed of crushed stone and sand with 1:1 ratio. With the knowledge of the commander of the supervision staff from the

Engineering Authority of the Egyptian Armed Forces, samples of siliceous sand and crushed stone were provided from private quarries of the Egyptian Armed Forces.

In addition to that, the sieve analysis curves of crushed stone and sand material are shown in **Error! Reference source not found.**, and **Error! Reference source not found.**. Also, the engineering properties of crushed stone as the general visual characterization of crushed stone samples of various sizes is white to light brown. The natural water content, volumetric weight, specific gravity of grains, gradient coefficient, uniformity coefficient is recorded in

Gravel			Sand			Silt			Clay	Gravel	Sand	Silt	Clay
Coarse	**Medium**	**Fine**	**Coarse**	**Coarse**	**Medium**	**Fine**	**Coarse**	**Medium**			**Coarse**	**Medium**	**Fine**

Table 2, and

Table *3*.

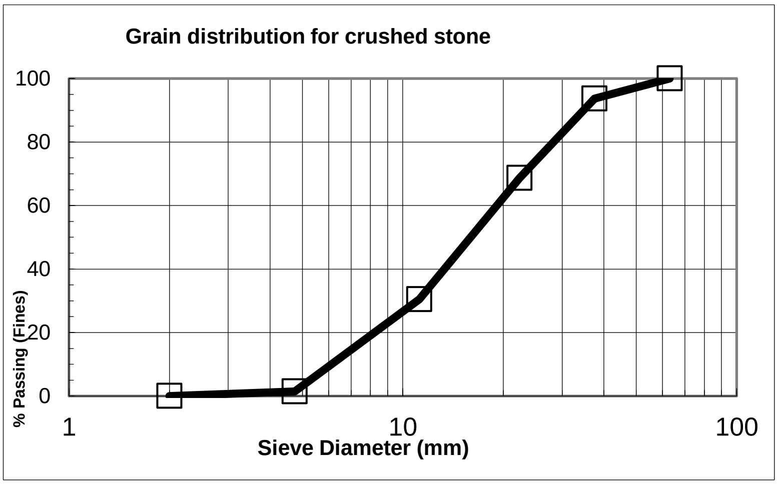

Fig. 2: Granular gradient curve for the crushed stone used in the replacement layers

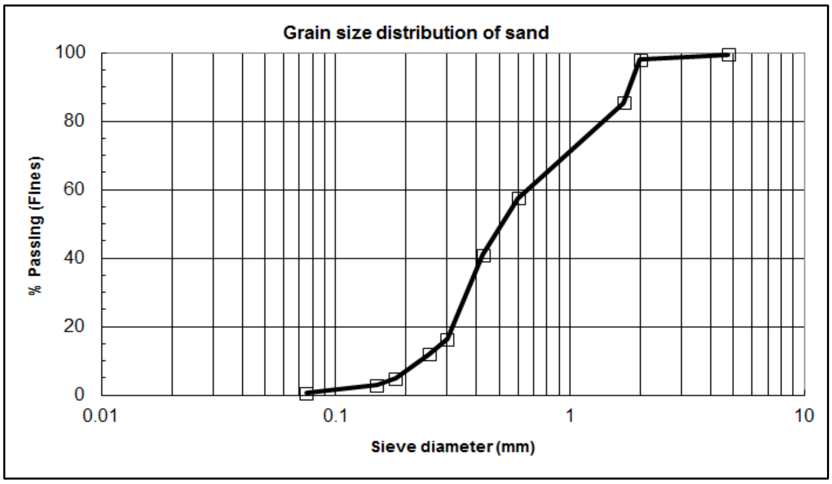

Fig. 3: Granular gradient curve for the sand used in the replacement layers

Gravel	Sand	Silt	Clay		Gravel	Sand	Silt	Clay

Coarse	Medium	Fine	Coarse	Coarse	Medium	Fine	Coarse	Medium			Coarse	Medium	Fine	

Table 2: Geometrical properties of crushed stone samples

$w_{nat.}$	G_s	Gravel	Sand	Fines	C_u	C_c
1.10 %	2.67	98.0 %	2.0 %	0.0 %	3.03	1.61

Table 3: Geometrical properties of sand samples

$w_{nat.}$	G_s	Gravel	Sand	Fines	C_u	C_c
1.72 %	2.68	1.5 %	98.2 %	0.3 %	2.82	0.75

2.2 Compaction Test

In the laboratory, the modified compaction test of the mixture of crushed stone and sand (1:1) was carried out using a modified Proctor device to determine the maximum dry density ($\gamma_{dmax.}$) and the optimum moisture content (OMC). Fig. 4 completes the results of the tests. Accordingly, the compaction parameters are record as, $\gamma_{dmax} = 2.10\ gm/cm^3$, and $OMC = 6.15\%$

In field, Table 4 show the values of moisture content (%), dry density (g/cm^3) and degree of compaction (%) for each replacement layer separately and for both sites, in order.

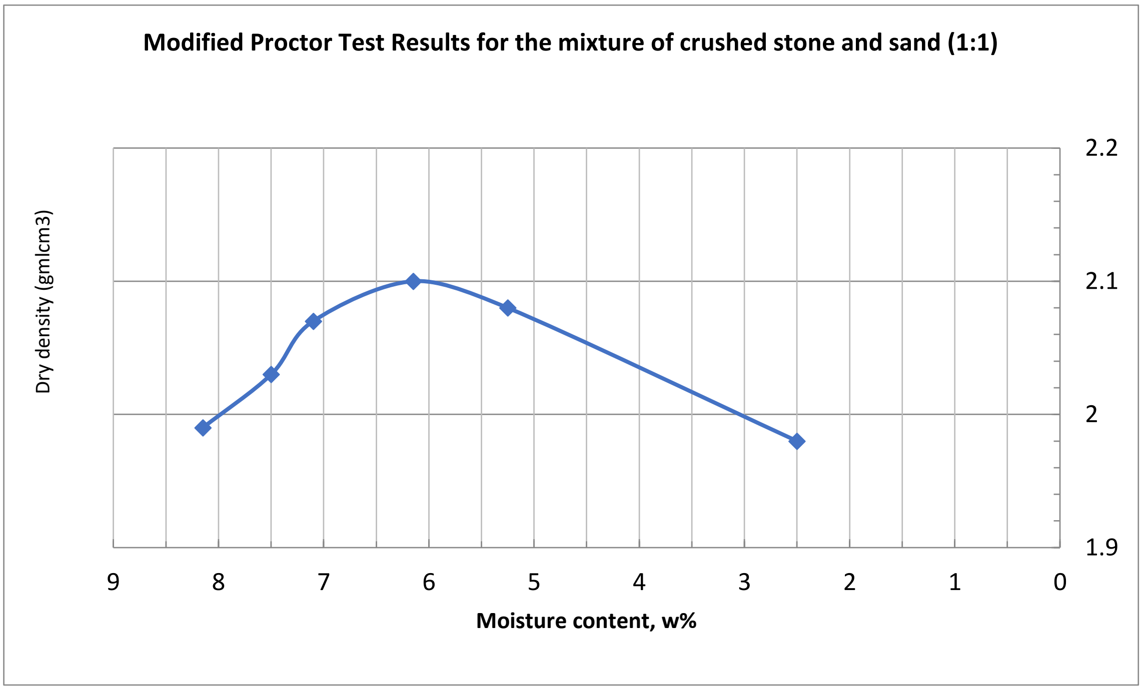

Fig. 4: Lab-Modified Compaction Test Results

Table 4: The average values of field compaction test, crushed stone and sand mixture (1:1) replacement layers

Layer No.	Layer 1	Layer 2	Layer 3	Layer 4	Layer 5	Layer 6	Average
Moisture content (%)	7.10	7.24	5.66	6.75	7.04	5.80	6.60
Dry density (gm/cm^3)	2.08	2.14	2.02	2.14	2.06	2.08	2.09
Compaction degree (%)	99	102	96	102	98	99	99.33

2.3 Plate Loading Test

The engineering tests and their measurements were earned out and evaluated according to Egyptian Code [5] or by the manner of testing as mentioned in soil mechanics handbooks as Bowles [2], El-Kasaby [6], Perkins [11], and Reznik [13]. The site contains many buildings. The excavation level from ground surface is 3m (D = -3m). It was suggested that using replacement layer of 1.5m thickness. Replacement layer constructed as 6 layers (each one 25cm) and compacted, as listed in

Table 5.

Plate bearing tests results contain the applied loads Q ton. The applied loads are measured by the gauge of hydraulic jack. For each plate loading tests the obtained results are indicated by curve as the relation between applied load Q and settlement. According to the results of plate loading tests. The ultimate bearing capacity can be estimated.

Table 5: The Conducted Plate loading tests in the Site, for each building area

Test Number	Replacement Layer Number	Level from ground surface (m)	Notes
1	0	-3.00	At excavation layer
2	1	-2.75	R.L. Thickness = 0.25m
3	2	-2.50	R.L. Thickness = 0.50m
4	3	-2.25	R.L. Thickness = 0.75m
5	4	-2.00	R.L. Thickness = 1.00m
6	5	-1.75	R.L. Thickness = 1.25m
7	6	-1.50	R.L. Thickness = 1.50m

III. RESULTS AND DISCUSSION

3.1 Excavation Level

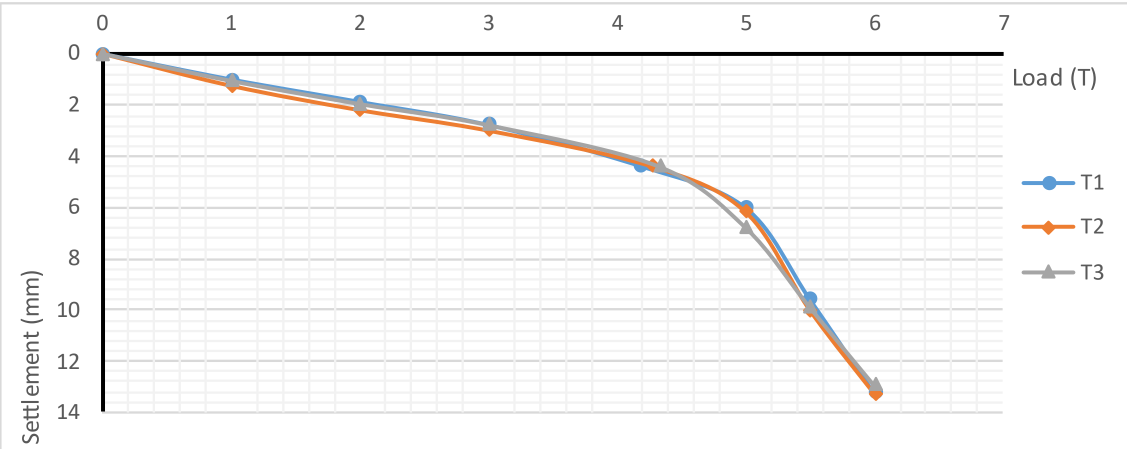

Fig. 5: Plate loading test result at excavation level

The results of plate loading tests on natural soil layer (at level -3m from ground surface) are shown in **Error! Reference source not found.**. It's clear that a gradual decline that occurs to the natural soil. So that the average ultimate bearing capacity for these results is 26.813t/m^2. At test 1 the $q_{ult.}$ = 26.313 t/m^2 at Q_{max} = 4.184 ton, while at test 2 the q_{ult} = 26.907 t/m^2 for Q_{max} = 4.278 ton, and finally the q_{ult} = 27.219 t/m^2 at Q_{max} = 4.328 ton with averages of q_{ult} (average) = 26.813 t/m^2.

3.2 First Replacement Layer Level

In the first replacement layer at level D = -2.75m, the curve in **Error! Reference source not found.** appears almost in the same shape as the curve of the natural soil, the ultimate bearing capacity ($q_{ult.}$) increases by 13.7 % with in perspective to the excavation level. At test 1 the $q_{ult.}$ = 29.108 t/m^2 at Q_{max} = 4.628 ton, while at test 2 the q_{ult} = 28.357 t/m^2 for Q_{max} = 4.509 ton, and finally the q_{ult} = 32.041 t/m^2 at Q_{max} = 5.413 ton with averages of q_{ult} (average) = 29.835 t/m^2.

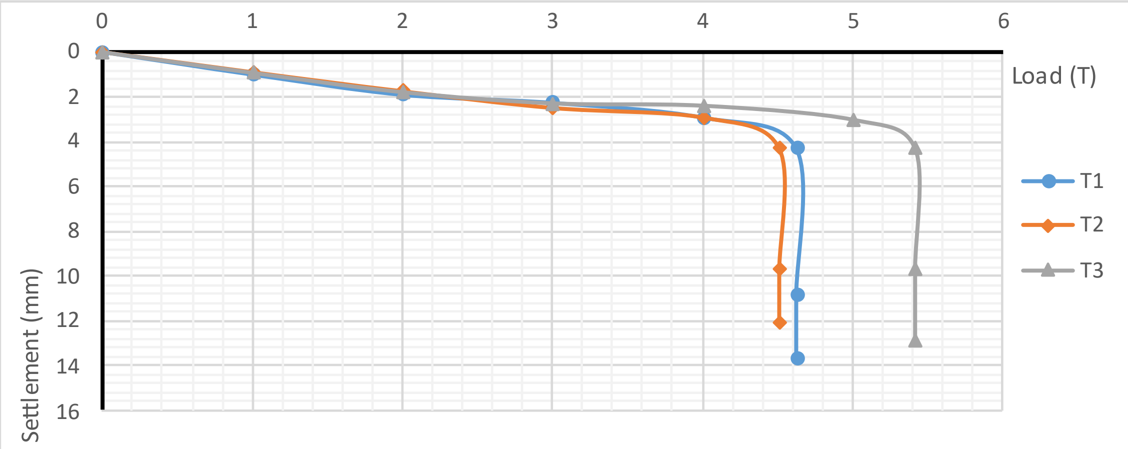

Fig. 6: Plate loading test result at first R.L. level No. (1)

3.3 Second Replacement Layer Level

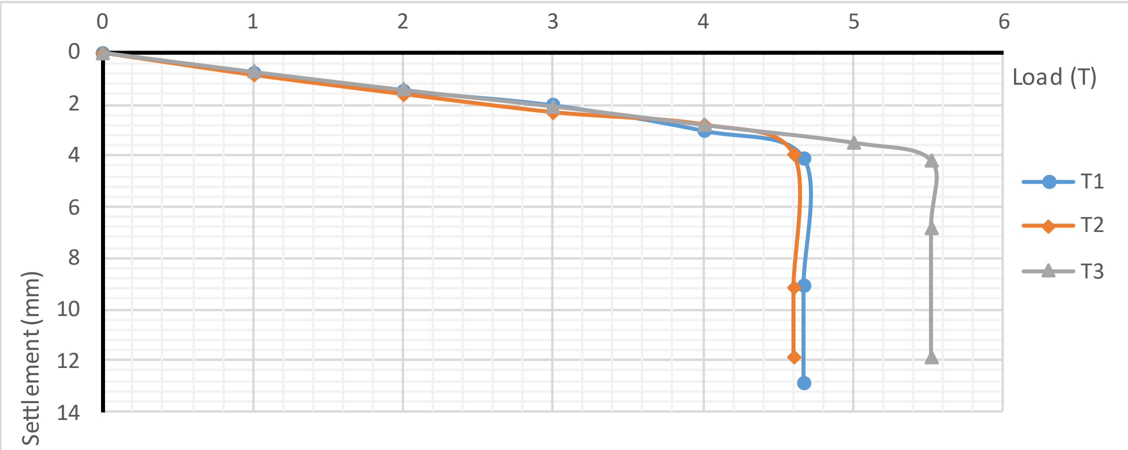

Fig. 7: Plate loading test result at second R.L. level No. (2)

After placing the second replacement layer and reached to (D = -2.5m). It is noted in **Error! Reference source not found.** that the average ultimate bearing capacity for these results increases 15.6% than that obtained from the result of excavation level. At test 1 the $q_{ult.}$ = 29.401 t/m^2 at Q_{max} = 4.675 ton, while at test 2 the q_{ult} = 28.918 t/m^2 for Q_{max} = 4.598 ton, and finally the q_{ult} = 34.687 t/m^2 at Q_{max} = 5.515 ton with averages of q_{ult} (average) = 31.002 t/m^2.

3.4 Third Replacement Layer Level

As illustrated in **Error! Reference source not found.**, The value of the average ultimate bearing capacity after placing the third replacement layer (D = -2.25m) has increased 20%. Knowing that the percentages of increasing and decreasing are proportional to the excavation level. At test 1 the $q_{ult.}$ = 31.664 t/m^2 at Q_{max} = 5.035 ton, while at test 2 the q_{ult} = 32.179 t/m^2 for Q_{max} = 5.116 ton, and finally the q_{ult} = 32.649 t/m^2 at Q_{max} = 5.114 ton with averages of q_{ult} (average) = 32.164 t/m^2.

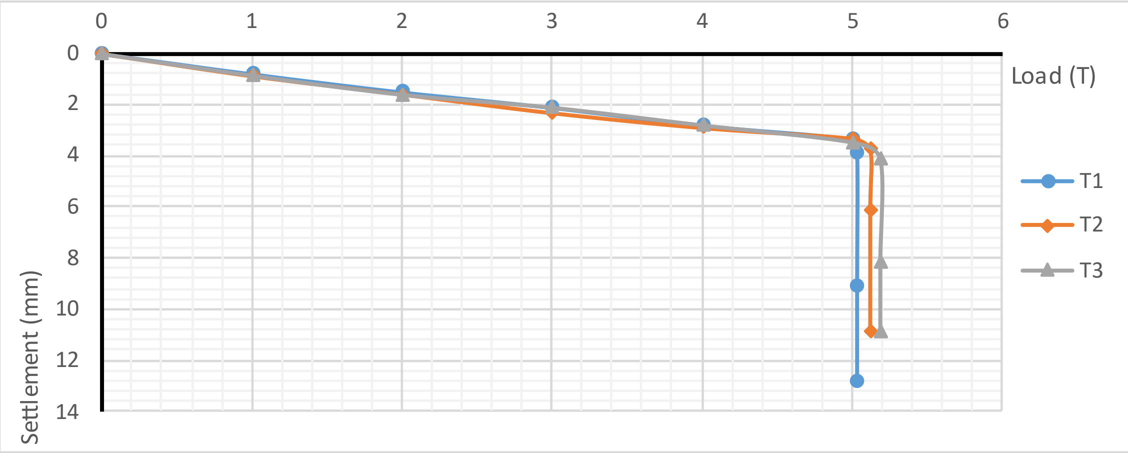

Fig. 8: Plate loading test result at Third R.L. level No. (3)

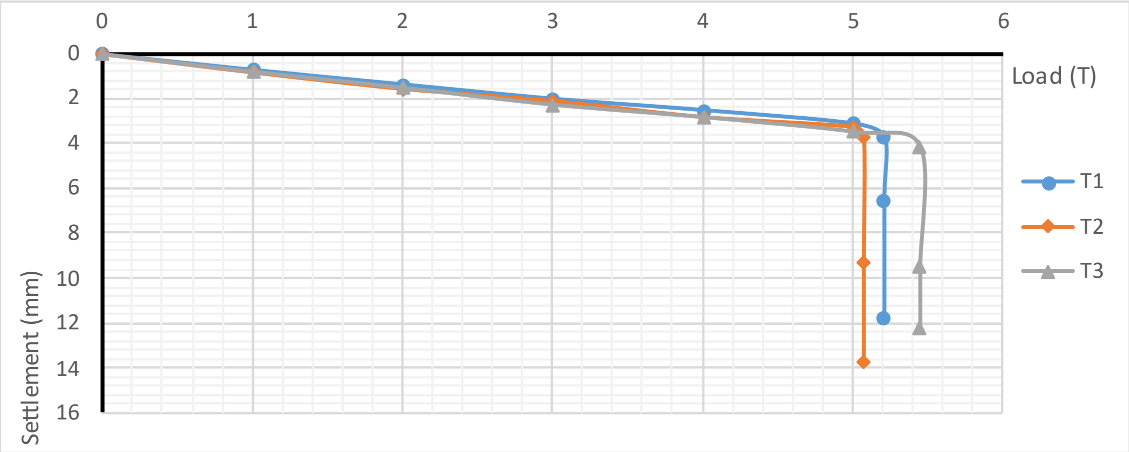

Fig. 9: Plate loading test result at Fourth R.L. level No. (4)

3.5 Fourth Replacement Layer Level

After placing the fourth replacement layer and reached to (D = -2.00m). It was noted in **Error! Reference source not found.**, the average ultimate bearing capacity increases 23%, then the excavation level. At test 1 the $q_{ult.}$ = 32.755 t/m^2 at Q_{max} = 5.208 ton, while at test 2 the q_{ult} = 31.908 t/m^2 for Q_{max} = 5.073 ton, and finally the q_{ult} = 34.256 t/m^2 at Q_{max} = 5.447 ton with averages of q_{ult} (average) = 32.973 t/m^2.

3.6 Fifth Replacement Layer Level

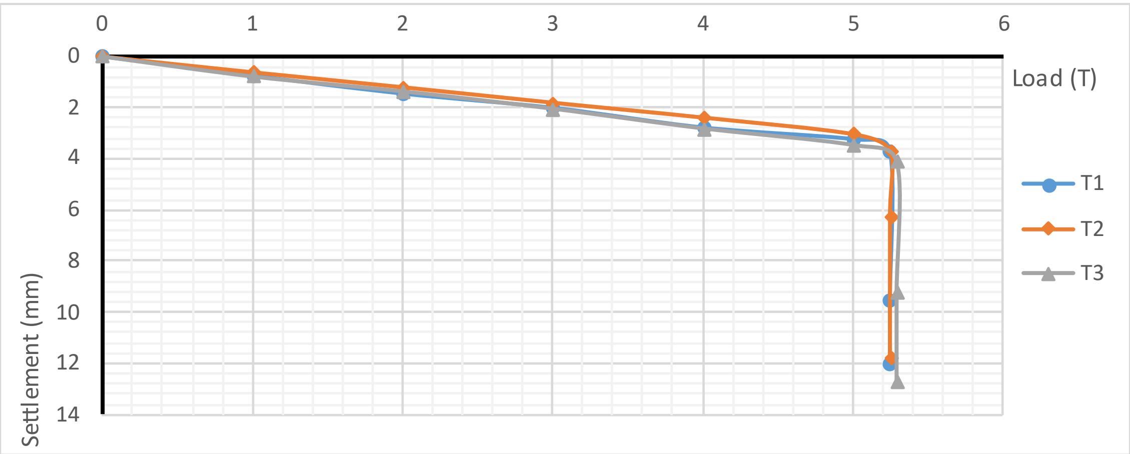

Fig. 10: Plate loading test result at Fifth R.L. level No. (5)

As illustrated in **Error! Reference source not found.**. After placing the fifth replacement layer and reached to (D = -1.75m). It was noted that the value of the average ultimate bearing capacity increases by 23.9%, proportional to the excavation level. At test 1 the $q_{ult.}$ = 32.964 t/m^2 at Q_{max} = 5.241 ton, while at test 2 the q_{ult} = 33.014 t/m^2 for Q_{max} = 5.249 ton, and finally the q_{ult} = 33.292 t/m^2 at Q_{max} = 5.293 ton with averages of q_{ult} (average) = 33.090 t/m^2.

3.7 Sixth Replacement Layer Level

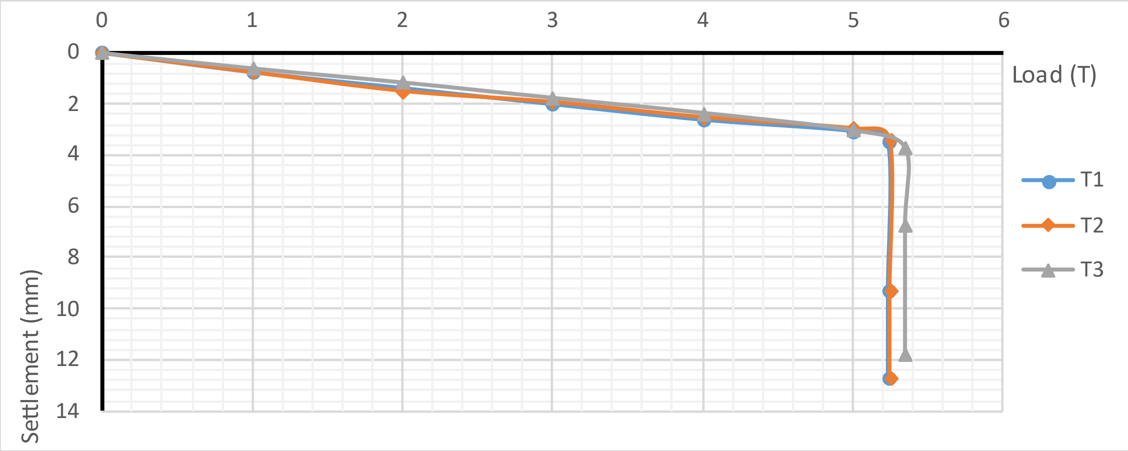

Fig. 11: Plate loading test result at Sixth R.L. level No. (6)

After placing the sixth replacement layer and reached to (D = -1.50m). The average of ultimate bearing capacity increases by 23.77% than that obtained from the result of excavation level. At test 1 the $q_{ult.}$ = 32.924 t/m^2 at Q_{max} = 5.235 ton, while at test 2 the q_{ult} = 33.017 t/m^2 for Q_{max} = 5.250 ton, and finally the q_{ult} = 33.620 t/m^2 at Q_{max} = 5.346 ton with averages of q_{ult} (average) = 33.187 t/m^2, **Error! Reference source not found.**.

3.8 Averages of Ultimate bearing Capacity

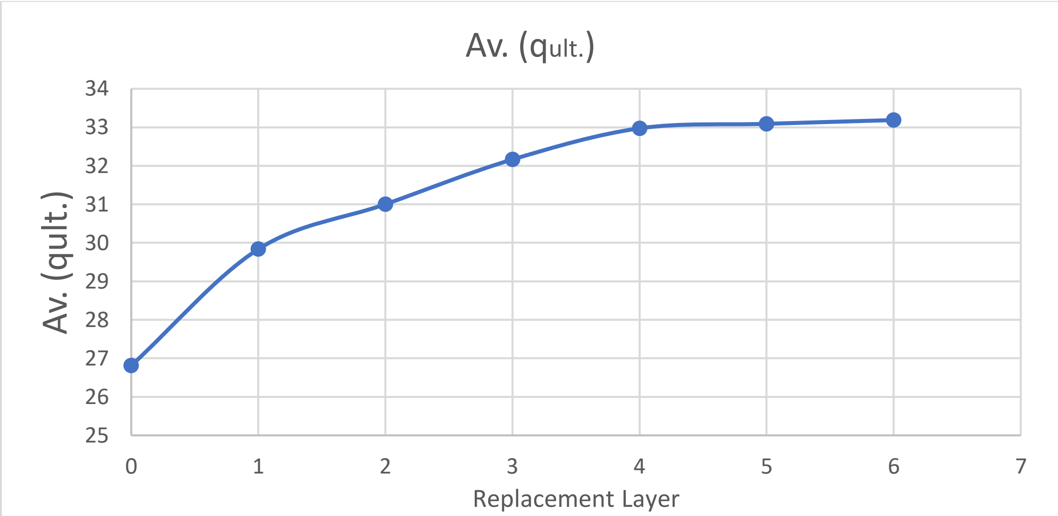

Fig. 12: Average (qult.) result at each layer

The ultimate bearing capacity increases by 11.3%, 15.6% and 20.0% after constructing the first, second and third replacement layer respectively. And 23.0% for the fourth replacement layer. Finally, a staidly increase is observed in the fifth and the sixth replacement layer recording 23.4% and 23.8% respectively, all these percentage were estimated from the natural soil as listed in Table 6, **Error! Reference source not found.**.

Table 6: Average ($q_{ult.}$) result at each layer

Soil Layers	AV. $q_{ult.}$ (t/m)	$q_{ult.}$ Increase (%)
Natural Soil	**26.813**	**-**
First	**29.835**	**11.3**
Second	**31.002**	**15.6**
Third	**32.164**	**20.0**
Fourth	**32.973**	**23.0**
Fifth	**33.09**	**23.4**
Sixth	**33.187**	**23.8**

IV. CONCLUSION

This research is using plate loading test to investigate the effect of replacement layers on the ultimate bearing capacity ($q_{ult.}$). These studies would help to better understand the relationship between replacement layer thickness and ultimate bearing capacity, and could lead to the development of improved design guidelines for replacement layer thickness.

According to the results obtained from plate loading tests at variant thickness of replacement layer, the following conclusion can be drawn the ultimate bearing capacity (q_{ult}) increased with the increasing of replacement layers thickness.

The results of this study have shown that the effect of replacement layer thickness on ultimate bearing capacity slightly after the fourth layer. in addition to that increasing replacement layer thickness beyond the fourth layer may be limited.

The replacement layers lead to the development of improve the design guide lines for constructions of foundation.

REFERENCES

[1] Ashraf, M.G., *"Bearing Capacity of Shallow Foundations on Non-Cohesive Soil"*, Journal of Geotechnical Eng., ASCE, Vol. 122, No. 2, pp. 167-168, (1997).
[2] Bowles, J. E., *"Foundation Analysis and Design"*, 5th Edition, McGraw-Hill, (2001).
[3] Coduto, D.P., Kitch, W.A., & Yeung, M.R., *"Geotechnical Engineering: Principles and Practices"*, Boston: Pearson, (2011).
[4] Das, B. M., *"Principles of Foundation Engineering"*, 8th Edition, Thomson Brooks/Cole, (2017).
[5] Egyptian Code of Soil Mechanics, *"Foundations Carrying Out and Designation"*, Part 2, 6th Edition, Laboratory Tests, Housing and Building National Research Center (HBRC), (2001).
[6] El-Kasaby, E.A., *"Soil Mechanics"*, Scientific Books House, Cairo, Egypt. (1993), (In Arabic language).
[7] Frankli, K., *"Pile Driving by Direct Displacement"*, Engineering, 208(5382), 566-567, (1969).
[8] Garber, M.; and Baker, R., *"Bearing Capacity by Variational Methods"*, Journal of Geotechnical Eng. Div., ASCE, No. 5, pp. 695-698, (1979).
[9] Hegazy, A.A., *"In-Situ and Laboratory Bearing Tests for Estimating Bearing Capacity of Shallow Footings Subjected To Inclined Loads"*, Ph. D. Thesis, Faculty of Engineering, Assuit University, Egypt, (1999).
[10] Mayerhof, G., *"Ground Engineering"*, John Wiley & Sons, (1967).
[11] Perkins, S.N., *"Bearing Capacity of Highly Frictional Material"* Geotechnical Testing Journal, Vol. 18, No. 4, pp. 450-462, (1995).
[12] Poulos, H. G., & Davis, E. H., *"Pile Foundation Analysis and Design"*, John Wiley & Sons, (1980).
[13] Reznik, Y.M., *"Rigid Plate Settlement on Soils with Varying Deformation Properties"*, Geotechnical Testing Jornal, ASTM, Vol. 18, No. 2, pp. 194-203, (1995).
[14] Terzaghi, K., & Peck, R. B., *"Soil Mechanics in Engineering Practice"*,2nd Edition, John Wiley & Sons, (1967).
[15] Tomlinson, M. J., *"Pile Design and Construction Practice"*, 5th Edition, Taylor & Francis, (2013).
[16] Tomlinson, M. J., *"The Bearing Capacity of Footings on Sands and Gravels"*, Proceedings of the 4th International Conference on Soil Mechanics and Foundation Engineering, London, England, 1, 169-190, (1971).
[17] Vesic, A. S., *"Analysis and Design of Shallow Foundations"*, John Wiley & Sons, (1973).
[18] Winterkorn, H.F., & Fang, H.-Y., *"Foundation Engineering Handbook"*, 3rd edition, Boca Raton, FL: CRC Press, (2006).
[19] El-Kasaby, El-Sayed A., et al. "Behavior of Square Footings Reinforced with Glass Fiber Bristles and Biaxial Geogrid." European Journal of Geotechnical Engineering, Vol..8, No.4, pp. 5-11, (2023).
[20] El-Kasaby, El-Sayed A., et al. "Enhancing Flexural Performance of GFRC Square Foundation Footings through Uniaxial Geogrid Reinforcement." International Journal of Civil Engineering and Structural Analysis, Vol..9, No.8, pp. 15-22, (2023)