Journal of Al-Azhar University Engineering Sector

Vol. 20, No. 76, July 2025, 821-833

NUMERICAL ANALYSIS FOR THE IMPACT OF THE TYPE OF REPLACEMENT SOIL ON THE BEHAVIOR OF EXPANSIVE SOILS BENEATH CONCRETE STRUCTURE

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Citation:

S. A. Badr, M. A. El-Sedeck , W. N. Abd Elsamee, Numerical Analysis For The Impact of The Type of Replacement Soil on The Behavior of Expansive Soils Beneath Concrete Structure. Journal of Al-Azhar University Engineering Sector, vol. 20, pp. 821- 833, 2025.

Received: 17 February 2025

Revised: 15 April 2025

Accepted: 03 May 2025

Doi:10.21608/auej.2025.361346.1781

ABSTRACT

Swelling soil are mainly can shrink and swell in response to moisture content changes, causing damage to structures, particularly light structures and pavement. This paper presents is looking for an answer to the question of : Dose soil replacement type affects the behavior of the foundation soil as well as the building straining action? By creating a numerical model for a six-story building constructed on expansive soil ,simulated using PLAXIS 3D V22 program. Building isolated footing system is used as the foundation system in the numerical model. The natural expansive soil used in the current study possesses high values of swelling pressure, swell potential, free swell, Liquid limit, plastic limit, shrinkage limit, and Plasticity index, which are 20 kg/cm2, 38.76%, 180%, 81%, 40%, 15%, and 14%, respectively. Replacement soils of : sand, sand:gravel (1:1), sand:gravel (1:2), sand:gravel (2:1) and gravel are used with thickness in range of 0.50m to 2.50 m to reduce expansive soil effects. Without replacement soil expansive soil causes heaving for the corner, edge and center footings by 20.73% ,19.29% and 17.88 respectively. Using replacement of : sand , sand:gravel (1:1) , sand:gravel (1:2), sand: gravel (2:1) and gravel with .thickness of 1.5 m decreased footing heave by about a percentage of 15% , 14% , 13%, 14% and 13% respectively. Replacement soil decreases the heaving of foundations , though it does't return the heaving to its pre-swelling value .

KEYWORDS: Expansive soil , Isolated footing , Swelling soil , Type of replacement soil , PLAXIS 3D V22 .

التحليل العددي لتأثير نوع تربة الاحلال على سلوك التربة القابلة للانتفاش اسفل المنشات الخرسانية

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الملخص

تتواجد التربة القابلة للانتفاش في مناطق عدة في جمهورية مصر العربية وتعد من اهم المشاكل الهندسية حيث انها تتمدد وتنكمش تبعاً لتغيرات محتوى الرطوبة الناتج عن المياه الجوفية او التسريبات السطحية مما يتسبب في انتفاش غير منتظم اسفل المنشات وبالتالي حدوث شروخ او تلف المنشآت الخرسانية ، خاصةً المنشآت الخفيفة والطرق و الأرصفة . تهدف الدراسة الحالية الى دراسة سلوك التربة القابلة للانتفاش اسفل الاساسات السطحة

للمنشات الخرسانية من خلال محاكاة نموذجًا عدديًا باستخدام برنامج PLAXIS 3D V22 لمبنى مكون من ستة طوابق مشيد على تربة لها طاقة انتفاش عالية حيث بلغت قيمة كل من ضغط الانتفاش , طاقة الانتفاش , الانتفاش الحر , حد الليونة , حد اللدونة , حد الانكماش الى ٢٠كجم/سم٢ , ٣٨,٧٦٪ , ١٨٠% , ٨١٪ , ٤٠٪ , ١٥٪ و 14% على التوالي . تم استخدام نظام القواعد المنفصلة و تم استخدام تربة احلال من الرمل , الرمل:الزلط (١:١) ، الرمل:الزلط (٢:١) و الرمل: الزلط (١:٢) والزلط وذلك بسمك يتراوح من ٠,٥ م , الى ٢,٥٠ م لدراسة تأثير الانتفاش للتربة على المنشأ . اظهرت الدراسة أن التربة القابلة للانتفاش تتسبب في حدوث انتفاش عالي دون استخدام تربة احلال حيث بلغت قيمة الانتفاش اسفل القواعد الركنية , الطرفية والوسطية الى ٢٠,٧٣٪ , ١٩,٢٩٪ و ١٧,٨٨٪ على التوالي . وعند استخدام تربة احلال من الرمل , الرمل:الزلط (١:١) ، الرمل:الزلط (٢:١) و الرمل: الزلط (١:٢) والزلط بسمك 1.5م يقل الانتفاش اسفل القواعد بنسبة ١٥٪ , ١٤٪ , ١٣٪ , ١٤٪ و ١٣٪ على التوالي.

الكلمات المفتاحية : التربة الانتفاخية ، القواعد المنفصلة ، التربة القابلة للانتفاش ، انواع تربة الاحلال ، بلاكسيز ثلاثي الابعاد .

1. INTRODUCTION

Expansive soils is extensive in some areas of Egypt. Geotechnical engineers did not recognize damages which associated with buildings caried on swelling soils until the late of 1930s [1]. The U.S. Bureau of the reclamation made first recorded observation about the soil heaving in 1938s. Then, many of researchers had pioneered researchs into swelling soils.

Because of their tiny size and the presence of the positive ions, high expansive clay soils have a high attraction for water [2]. When wet, the expansive soils swell and stick, and they shrink when dry, leaving broad fissures or a puffy appearance (desiccated clay). The water intake into the montmorillonites, a mineral of expanding lattice clay found in swelling soils, is frequently blamed for the swelling. Montmorillonite is formed up of a core octahedral sheet, commonly inhabited by the aluminium or magnesium, sandwiched between two sheets of tetrahedral silicon sites to create a 2 to 1 lattice structure [3].

The soils in the medium to high expansion potential category require special considerations in the design of structures founded on these soils. They also require adequate precautionary measures to prevent excessive structural damage. Soil treatment using various techniques is commonly used to improve the expansive soil on the site to avoid excessive swelling , some of the most popular treatment methods are as follows [4]:-

Chemical Treatment: Chemical stabilization one of the most common methods used to improve expansive soil properties. Chemical stabilization includes the mixing or injecting of chemical substances into the soil. Lime, cement, asphalt, calcium chloride, sodium chloride, and paper mill wastes are common chemical stabilization agents. The effectiveness of these additives depends on the soil conditions, stabilizer properties, and type of construction. The selection of a particular additive depends on costs, benefits, availability, and practicality of its application.

Mechanical Treatment: Mechanical methods are consider one of the cheapest and most common ways to treat expansive soils, as they depend on the use of inert raw materials, and these materials are often inexpensive, such as sand, stones, gravel and other inert materials. The idea of treating expansive soils by mechanical methods depends either on removing all or part of the bulging soils (in case the bulging soil depth is large) and replacing it with other inert soils such as sand and gravel or broken stones, or it depends on mixing the expansive soil with inert materials in order to reduce the proportion of clay in the soil.

Soil Replacement: One of the most common mechanical methods in the treatment of swelling soil is the useing of replacement soil, mixing the soil with sand, or making columns of stone among the expansive soil. The following is a list of the most important and most common mechanical methods used in the treatment of expansive soil.

Using replacement sandy layer in a model of the swelling soil under isolated footing with the use of a replacement soil of sand with a thickness equal to 1/3, 2/3, 1 the width., had shown that the maximum reduction percentage of footing heave was 48.68% when using the sand cushion thickness equal to the width of footing [5].

Three mixed different types of expansive soil with sand soil in proportions of 20%, 40%, 60%, and 80% by weight of the dry soil mass to improve characteristics of expansive soil. Test results show that the swelling pressure and swelling potential values reduce by increasing in sand soil content for three different types of expansive soil [6].

The behavior of using different types of soils as a substitution soil beneath footing constructed on swelling soil had been investigated. A four- floors typical construction built on swelling soil had been applied in the model. ABAQUS, Finite element analysis Programm, using simulated model. It founded that , using layers of another soil as substitution system reduced footing heave by 20% , 31% , and 40% respectively when using layer's depth of 1.0 m,1.5m and2.0m. And the differential heaving between foundations decreased by 25% , 31% , and 38% , respectively [7].

This paper presents a numerical model for a six-story residential building carried out on highly expansive soil for the site of the new branch of Al-Azhar University in Al-Kawthar city, Sohag government, for studying influencing of the usage of substitution soils of : sand , sand to gravel [1 : 2] sand to gravel [1 : 1] , sand to gravel [2 : 1] and gravel on the swelling behaviour and engineering properties of soil.

The parametric study was numerically carried out using PLAXIS 3D V22 program Finite element analysis explained and identified the decrease in the heaving on the shallow foundation constructed on this soil. The results also confirmed the swelling behaviour mechanism and showed how to reduce the heaving of the foundation due to soil swelling.

2. NUMERICAL MODEL

A building consists of six floors at the new branch of Azhar University in Sohag governorate was selected for this study. The building was constructed on highly swelling soil with isolated footings as shown in **Fig. 1** on replacement layer of sandy soil [8].

The model boundaries were selected as 35 *35 *10 m for soil so as to avoid any of strain and restrictions localizing in the analyzing. The building building under study has neen considered as a reinforcement concrete construction with plan of (B x L) =15.00 m x L=15.00m and 6 typical stories eath height of 3.00 m, a simple global finite element mesh of the model is created in setting as medium to represent actual distribution of stresses as shown in Fig. 2. Each floor has three bays all of them with a 5.00m dimension in both X and Y directions. The foundation level (F.L.) is at depth of 1.50 m below ground surface. Square isolated footing are assumed to be used in the present study. All flooring were assumed to be flat slabs with 0.20 m thickness fixed to columns of 0.50m x 0.50m dimensions. The exterior columns are rested on square footing of : 2.0 m*2.0 m *0.8 m dimensions (F1 model), while the internal columns are rested on square footing of : 3.0m* 3.0m* 0.8m dimensions (F2 model) as shown in **Fig. 2.**

In this model, the isolated square footings were connected together with ground beams of 300*800 mm . The model of soil applied in the presented study with 10.00m thickness were contain two layers of soil :

- Replacement of sandy soils of 0.50m , 1.00 m ,1.50m, 2.00m and 2.50m thickness .
- Swelling soil which lasts until the ending of the soil's model.

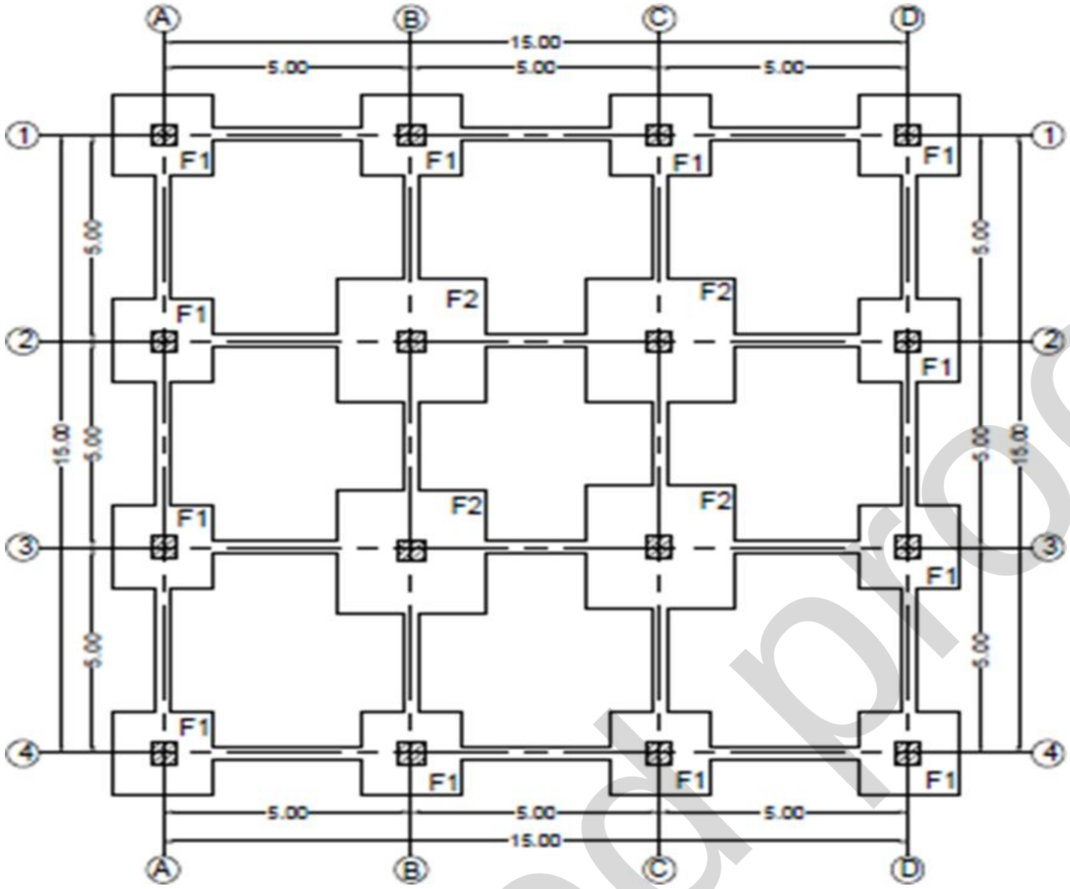


Fig. 1: The foundation system of building under study

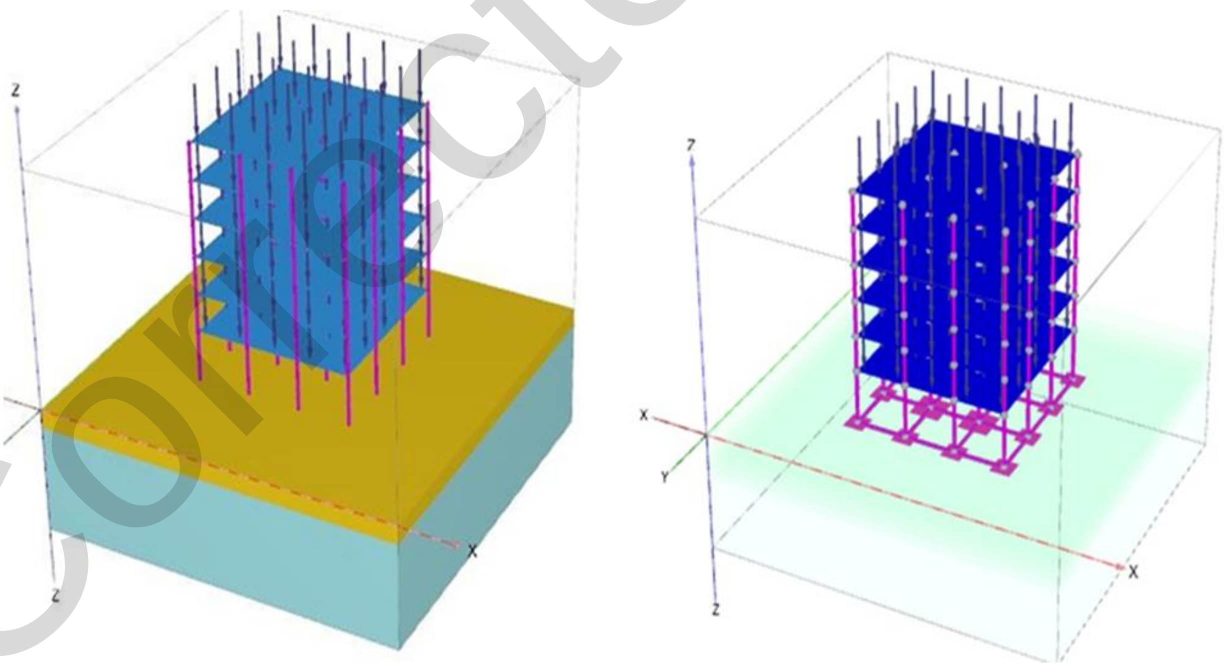


Fig. 2: Numerically Modelling for the building under study [8].

2.1. Materials and parametric study

Five types of soils were used in the parametric study: swelling soil, sand , sand to gravel [1:2] sand to gravel [1:1] , sand to gravel [2:1] and gravel. All data of swelling soils were specific from tests which were performed to on tested sample extracted site of the building under study [9,10].

In the numerical analysis model, the properties of used materials are listed in **Tables (1&2)** . Structure materials used includes the material of : foundation, ground beam, column and flooring. Soil material includes expansive soil, replacement soils.

Table 1: Input soil roperties used in the numerical analysis [9]

Factors	Expansive soil	Sandy soil	Sand : Gravel (1:1)	Sand : Gravel (1:2)	Sandy : Gravel (2:1)	Gravely soil
Model Type	Mohr-Coulomb	Mohr Coulomb	Mohr Coulomb	Mohr Coulomb	Mohr Coulomb	Mohr Coulomb
Type of material behavior	Undrained	Drained	Drained	Drained	Drained	Drained
Unsaturated unit weight, γ unsat (kN/m^3)	21.7	20.60	20.10	24.13	23.09	16.48
Saturated unit weight, γsat (kN/m^3)	23	21.50	21.36	24.16	23.18	19.81
Void ratio e	0.37	0.3927	0.4255	0.1752	0.2248	0.6667
E (kN/m^2)	7500	100.0E3	140.0E3	160.0E3	160.0E3	180.0E3
Poisson's ratio, υ	0.3	0.35	0.31	0.29	0.33	0.27
Drained cohesion, c_u (kN/m^2)	50	1	1	1	1	1
Friction angle, φ	30°	37°	39°	40°	38°	45°
Dilatancy angle, ψ	0	7°	9°	10°	8°	15°

Table 2: Input structure materials roperties used in the numerical analysis [9] .

Factor	Unite	Slabs	Footings	Ground beams	Column
Type of Material		elastic	elastic	elastic	elastic
Cross section	m^2			0.24	0.25
Thickness	m	0.2	.08		
Density	KN/m^3	24	2.4	24	24
Ratio of Poisson		0.2	0.2	0.2	0.2
Elastic modules	KN/m^2			$2.20*10^6$	$2.20*10^6$
Moment of Inertia	m^4			$12.8*10^{-3}$	$5.2*10^{-3}$

2.2. Generation meshs

An average element size and number of 15-node triangular elements are determined by the setting of global coarseness. A simple global finite element mesh of the model is created in setting as medium to represent actual distribution of stresses.

2.3. Transmitted load to the beaing soil

Different loads acting on the structure's floor:

- Vertical D.L , from the sum of D.L of (floors, walls and flooring covers) are calculated as = (25.00 x 0.2) + 1.50 +1.50 = 8.00 kN/m²
- Vertical L.L , from the L.L on the construction which equivalent to 5.00 kN/m². Then , the sum loads acting on surfaces of floors is equivalent to 8.00+5.00=13.00 kN/m² in (Z ↓) direction .

According to the Egyptian Code of Practice (ECP) [1١] , the footing contact pressure is estimated to be 200 kN/m2, while the natural expansive soil used in the current study possesses high values of swelling pressure which are 2000 kN/m2 according to the results of oedometer test of three samples of undisturbed expansive soil and three samples of remolded expansive soil are showed in the **Table 3** [9].

Table 3: The results of oedometer test of three samples of undisturbed expansive soil and three samples of remolded expansive soil [9]

Soil sample	Undisturbed Sample			Remolded Sample		
	No. 1	No.2	No.3	No.1	No.2	No.3
Swelling potential (%)	40.5	39.4	36.38	45.38	47.33	45.83
Average Swelling potential (%)	38.76			44.51		
Swelling pressure (kg/cm^2)	22	20	18	32	36	33
Average Swelling pressure (kg/cm^2)	20			34		

Therefore, a replacement layer was used to minimize the effect of the high potential heave of the expansive soil.

In general, it is significant using another soils as substitution soil to avoid occurrence heaving to upward as the construction's loads are light weights and it can't avoid the heaving of swelling the soil.

2.4. Calculation stages

After completing modeling of the finite element of the described problems, the actual finite element calculations can be executed. For this type of problem, three stages are selected for finite element calculations. The first stage without swell represents the construction of the foundation and superstructure ,at this stage; the activation of elements of (plat , beam) , and surface loads . The second stage without replacement stage is the the stage of application of the potential of swelling for expansive soil , at this stage; it will be activated the positive volumetric strain in the cluster of expansive soil. The third stage for using replacement soil with thickness (h) equal to 0.٥ m, 1.00 m, 1.50 m, 2.00 m and 2.50 m. Soils used in the replacement are sand , sand:gravel (1:2) sand:gravel (1:1) , sand:gravel (2:1) and gravel . The explained cases in the presented search are showed in the **Table 4.**

Table 4: Cases Studied in The Presented Search

Replacement soils types	Replacement soil's thicknesses [h] m	Case's Number
sand	0.5	1
	1	2
	1.5	3
	2	4
	2.5	5
sand : gravel (1 : 1)	0.5	6
	1	7
	1.5	8
	2	9
	2.5	10
sand : gravel (1 : 2)	0.5	11
	1	12
	1.5	13
	2	14
	2.5	15
sand : gravel (2 : 1)	0.5	16
	1	17
	1.5	18
	2	19
	2.5	20
gravel	0.5	21
	1	22
	1.5	23
	2	24
	2.5	25

By applying of D.L and L.L, It would be starting to apply each of the heaving and shrinking actions independently [12]. A positive of 26.40 % volumetric strain was applied on the swelling soil's clusters in the simulation of swelling of the expansive soil layers. This volumetric strain's value was taken from the average of heaving rate under 2.0 kg/cm2 of stresses (regular stresses caused by building's loads) for the swelling soils applied as undisturbed samples as showed in **Fig. 3** [9]. In fact, the source's position of the degree of overload and moisture efficient pressure has an effect on the rate at which expansive soil would normally swell. However, a volumetric strains was evenly acted on the total thickness of the layers of swelling soil in the analyses presented for simplification [1٣].

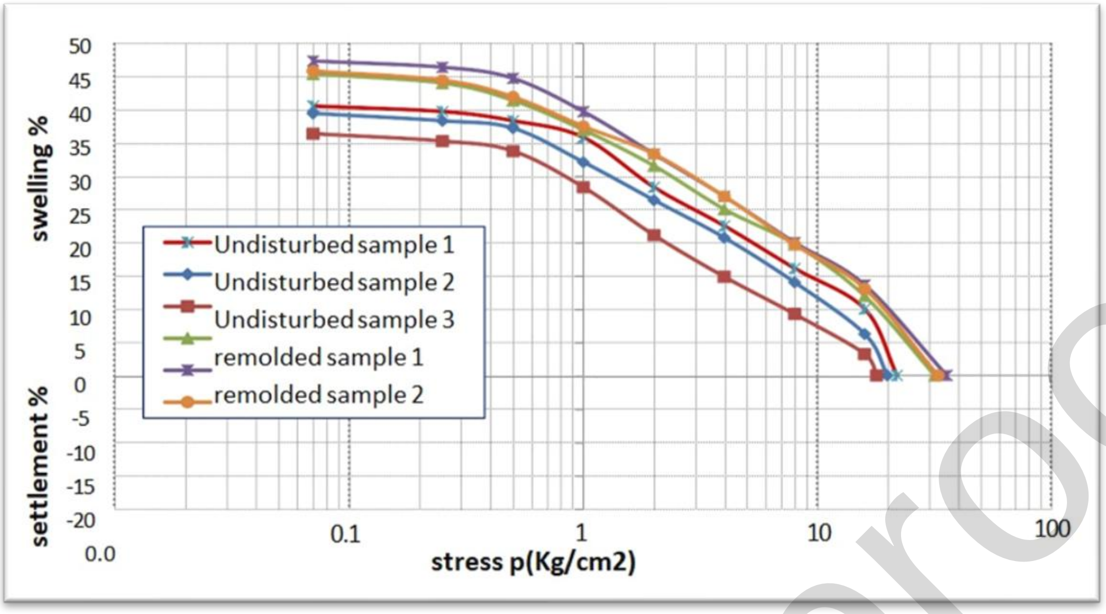


Fig. 3: Swelling - log p curves for three samples of undisturbed expansive soil and three samples of remolded expansive soil [8].

3. RESULTING AND DISCUSSION

For studying impact of the usage of replacement layers of soil on behavior of square footings which rested on swelling soils, a Finit element investigation was applied on the concrete construction without and with replacement of different soil types .

The heave and moments induced in corner, edge and middle footings were numerically investigated with the variation of replacement type and thickness.

3.1.Heave of footings impact of layers thickness of replacement soils on the performance of faundation

The impact of replacement layer type and thickness on heave of corner, edge and midle footings are represented in **Fig. (4-a), (4-b) & (4-c)** respectively. The reduction in footing heave is estimated as listed in **Table 4.**

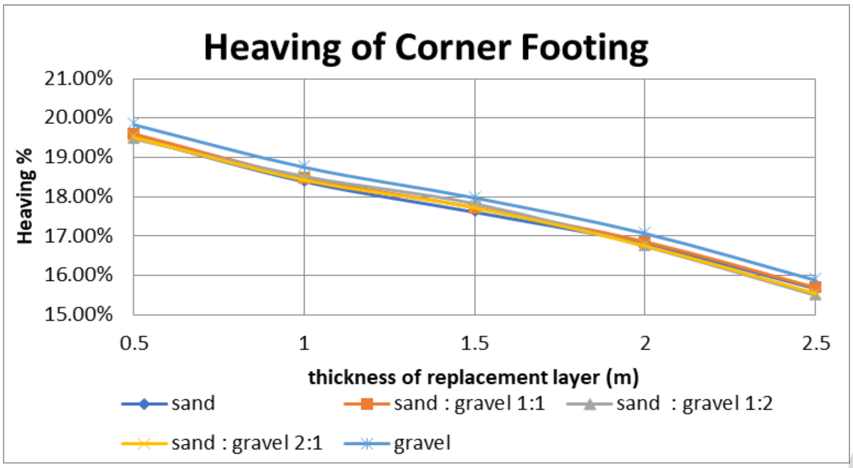
3.1.1. Heave of footings:

The impact of increment in the layer's thickness of replacement soils on soil's heaving beneath each corner,side and middle footings are showes in Fig 4.

The heaving ratio is expressed by the percentage of the total heave (swell) to the initial case height of soil's surface under the foundations as follows:

- HR = (Hf−Hi)/ Hi ∗ 100 (%) ………………………………………… Where:
- HR= Heaving percent Ratio (%)
- Hf = final Height (m)
- Hi = initial Height (m)

It was noted that, the heaving of soils decrease with the increment of thicknesses of replacement soils . And it so with reducing actireplacement type and ve depth of swelling soil.



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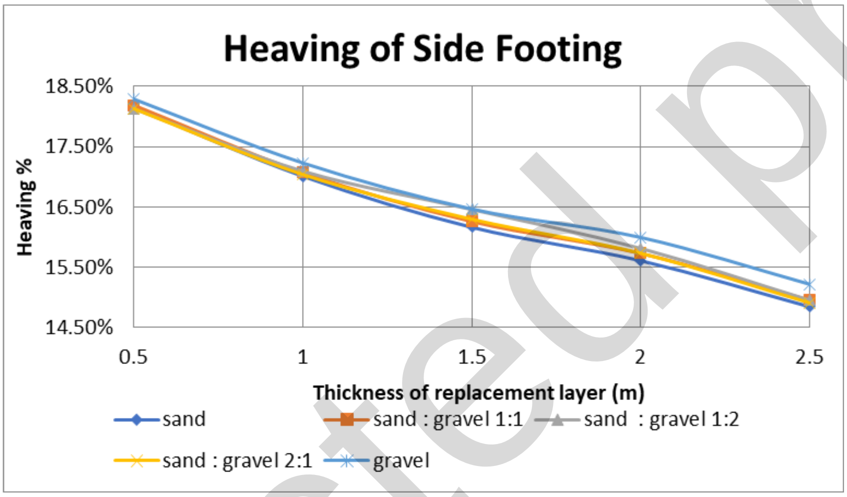

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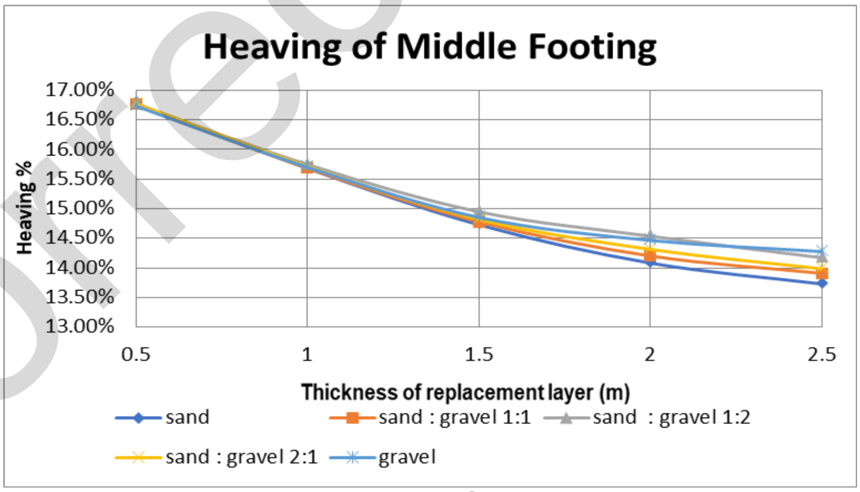

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Fig. 4: Effect of replacement layer type and thickness of on heave of footings:

(a) Corner footings, (b) Edge footings, and (c) Middle footings

3.1.2. The reduction of heaving under footing :

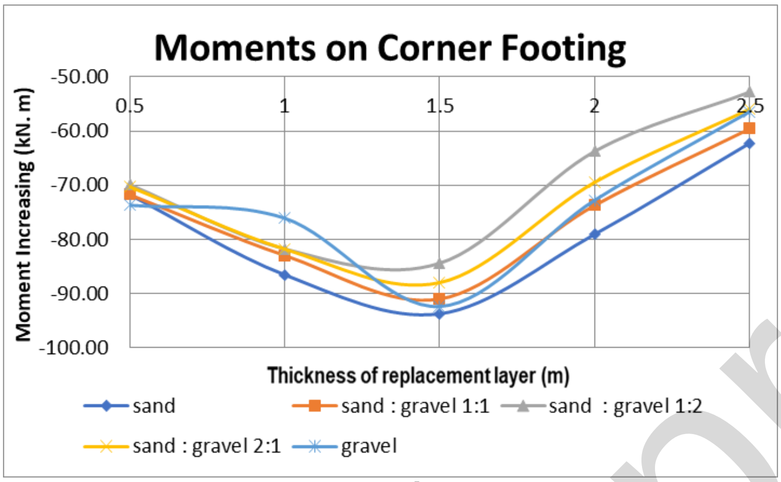
From **Fig. 4 and Table 5** it can be observed that, the heave of swelling deposit decreases with the increase of thickness of replacement layer, with general reduction in the range of 6.00% to about 20% for thickness of 0.50 to 2.50 m respectively for all types of replacement soil.

Table 5 : Reducing in footing's heave with variation of type and thickness of replacement layer

Replacement types soils	thickness of soil [m]	Reducing the heaving [%]		
		Corner's footings	Side's footings	Middle's footings
sand	0.5	5.85%	5.92%	6.18%
	1	11.30%	11.83%	12.30%
	1.5	15.04%	16.22%	17.63%
	2	18.96%	19.09%	21.25%
	2.5	24.41%	23.05%	23.22%
sand : gravel (1 : 1)	0.5	5.34%	5.67%	6.13%
	1	10.74%	11.47%	12.19%
	1.5	14.38%	15.68%	17.26%
	2	18.58%	18.43%	20.48%
	2.5	24.21%	22.45%	22.13%
sand : gravel (1 : 2)	0.5	5.32%	5.69%	6.19%
	1	9.95%	11.08%	11.91%
	1.5	13.33%	14.38%	16.39%
	2	18.59%	17.75%	18.69%
	2.5	24.66%	22.21%	20.73%
sand : gravel (2 : 1)	0.5	5.47%	5.86%	6.25%
	1	10.72%	11.54%	12.17%
	1.5	14.14%	15.39%	17.16%
	2	18.81%	18.32%	19.99%
	2.5	24.68%	22.60%	21.83%
gravel	0.5	4.26%	5.01%	5.95%
	1	9.48%	10.51%	11.77%
	1.5	13.23%	14.48%	16.53%
	2	17.61%	16.93%	18.71%
	2.5	23.34%	20.96%	19.77%

3.2.Moment Induced on Footings:

The relationships between the thicknesses of replacement layer and the induced footing's moment are shown in **Fig. 5** . The results show that, with the increase of thicknesses of replacement layer and the induced bending moments on footings decreases with thickness of about 1.50 m, then it returns to gradually increase again.



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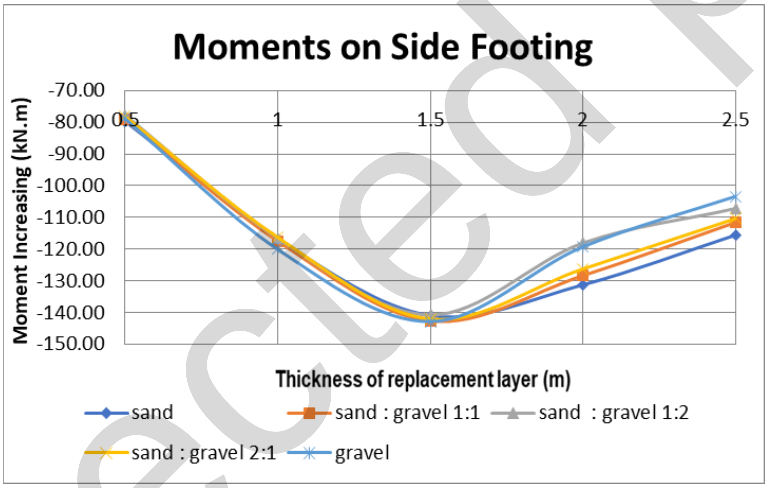

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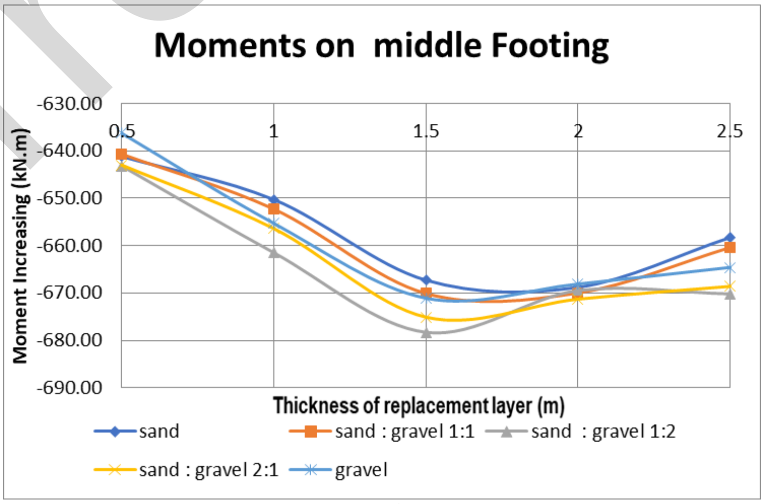

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Fig. 5: Relationship between replacement soil thickness and increasing in footing moment for: A-corner footing B-side footing C-middle footing

It is possible to explain that the partial replacement of expansive soils with compacted granular fill may be assumed as a suitable means to improve the behavior of expansive soil however, this is probably not the case for more than 1.5m depth replacement, as it may have the opposite effect by worsening the condition of the soil (behavior) due to deeper infiltration (saturation / loss of suction) of the subgrade resulting in heave due to the excavation and the granular nature of the replacement will potentially introduce more water to the subgrade; If the excavation is allowed to dry prior to placing the granular material it will propagate the 'suction profile' deeper creating an increased expansion potential and the corners of granular replacement will dry more than the center , which in turn may cause differential heave / shrinkage.

SUMMARIES AND CONCLUSIONS

From the present numerically study for the effect of thickness and type of replacement layer on the heave and bending moments induced from swelling deposit on 6 R.C. skelton floor building on isolated foundation system, the following conclusions are drawn:It is observed that the thickness of replacement soil and swelling action have a substantial effect on the heaving and moments of footing as the following:

1) It is observed that the thickness of replacement soil and swelling action have a substantial effect on the heaving and moments of footing as the heaving of footing decreasing with the increasing of thickness of replacement soil , but the effect of swelling soil on footing moment decreased by increasing thickness to 1.5m thickness, then it returns to increase again .
2) The heave of swelling deposit decreases with the increase of thickness of replacement layer, with general reduction in the range of 6.00% to about 20% for thickness of 0.50 to 2.50 m respectively for all types of replacement soil.
3) In spite of the variation of material of replacement layer does not show significane diffrences on the reduction on heave of swelling soil, sandy soil with maximum thickness of 1.50 m seems to be the most practical and economical technique.The value of the remaining heaving after replacement must also be considered into account in the step of designing foundations and reinforcement to avoid damage to reinforcement concrete.
4) The value of the remaining heaving after replacement and induced bending moment must also be considered into account in the step of designing foundations and reinforcement to avoid damage to reinforcement concrete.

CONFLICT OF INTEREST

The authors have no financial interest to declare in relation to the content of this article.

References

[1] F. H. Chen, Foundations on Expansive Soils, Elsevier Science Publishers B. V, 1988.

[2] R. W. Day, Geotechnical and Foundation Engineering Design and Construction, McGraw- Hill Companies, New York, 1999.

[3] P. E. Cernica, Geotechnical Engineering: Soil Mechanics, John W. and Sons, New York-Chichester-Brisbane-Toronto-Singapore, 1995, 453 pages.

[4] D. John, D. J. Nelson and Miller, Expansive Soils: Problems and Practice in Foundation and Pavement Engineering , 2nd Edition, 2015.

[5] G. E. Abdelrahman, G. Y. Youssef and A. E. Abdeltawab, " Effect of Sand Cushion Thickness and Lateral Extension on Heave of Remolded Swelling Soil" , Advancements in Geotechnical Engineering, SUCI, pp. 155–163, 2021. https://doi.org/10.1007/978-3-030-62908-3_12.

[6] S. M. ElKholy , "Improving the Characteristics of Expansive Soil Using Coarse-grained Soil" , Journal of Engineering and Computer Sciences, Qassim University, Vol. 1, No. 2, pp. 71-81, July 2008/Rajab 1429H .

[7] D. Abdelmoneim, M. El-Taher, S. A. Akl and H. H. Mamlouk , “Analysis of replacement layer properties and its effects on a typical building on swelling clay” , Public Works Department, Faculty of Engineering, Egypt Suez canal University, Egypt, 2018.

[8] W. H. Abd El-Samea, Y. M. Mowafy, M. A. Abd El- Naiem and A. R. Towfeek, “Numerical analysis of shallow foundation on expansive soil,” Journal of Al-Azhar University Engineering Sector, Vol. 17, No. 63, pp. 480 – 501, April 2022.

[9] W. H. Abd El-Samea, Y. M. Mowafy, M. A. Abd El- Naiem and A. R. Towfeek, "Treatment of expansive soils using Nano silica and rock powder" in Conf. Al-Azhar Engineering Fifteenth International Conference 2021.

[10] M. Abd El Raouf and K. M. M. Bahloul, “ Study the behaviour of expansive soil using finite element analysis,” Journal of Al-Azhar University Engineering Sector, vol. 20,Vo.74, pp.143–154, 2025.

[11] ECP202 – 2001, Egyptian Code of Soil Mechanics and Foundations, Edition – 2009, Egypt, 2009.

[12] A. I. Mostafa and A. S. Mohamed , “Finite element modeling of innovative shallow foundation system for reactive soils,” Int. J. of GEOMAT, Vol. 1, No. 1 (Sl. No. 1), pp., 78-82, Oct. 2011. Geotec., Const. Mat. and Env., ISSN: 2186-2982(p), 2186-2990(O), Japan.

[13] B. S. Al-Busoda and H. O. Abbas , “Numerical Simulation of Mitigation of Soil Swelling Problem under Communication Tower Using Helical Piles,” Journal of Geotechnical Engineering (JoGE), 4(3), 2017 .