Journal of Al-Azhar University Engineering Sector

Vol. 17, No. 63, April 2022, 480 - 501

NUMERICAL ANALYSIS OF SHALLOW FOUNDATION ON EXPANSIVE SOIL

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Received: 30 Nov. 2021 Accepted: 8 Jan. 2022

ABSTRACT

Expansive soils are mainly soils or rock materials that can shrink and swell in response to moisture content changes. Deformation of such soils is greater than elastic deformation and cannot be predicted by classical elastic plastic theory. Expansive soils cause damage to structures, particularly light structures and pavement. This paper presents a numerical model for a six-story building constructed on expansive soil located in the new branch of Al-Azhar University in Al-Kawthar City, Sohag government. A numerical model was simulated using PLAXIS 3D Foundation V20 software programme. The isolated footing system and mat foundation system are used in the numeric model. Replacement sandy soils and expansive soils treated by adding 20% lime stone powder and 2%Nano Silica are used with thickness 0.75m, 1.50m, and 2.25m to reduce expansive soil effects. The main results show that, expansive soil causes an increase in footing moment, ground beam moment, and mat foundation moment by 100%, 300% and 122% respectively, without using replacement soil. Replacement soil lowers the effect of swelling soil on footing moment, but it does not restore it to its pre-swelling value. Using replacement sandy and treated soil with thickness 2.25m decreased footing moment, by 75% and 70% respectively, ground beam moment by 100% and 83% respectively, and mat foundation moment by 55.33% and 52% respectively, from its value without using replacement soil. The extra moments should be taken into account in practice for the proper design of the foundation concrete section and reinforcement in order to avoid concrete damage.

KEYWORDS: Expansive Soil, Isolated Footing, Ground Beam and Mat Foundation

التحليل العددي للاساسات السطحية المنشأة على تربة انتفاشية- قابلة للانتفاش

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الملخص العربي :-

تتواجد التربة القابلة للانتفاش على نطاق واسع فى جمهورية مصر العربية وخاصة فى المدن العمرانية الجديدة التى شهدت تطورا كبيرا فى الاونة الاخيرة. تتسم التربة القابلة للانتفاش بقدرتها العالية على التمدد والانكماش عند تعرضها لدورات من الترطيب والجفاف مما يؤدى الى حدوث تباين فى درجات الهبوط ينتج عنه حدوث شروخ فى المنشأت المقامة عليها قد تصل الى حد الانهيار. تهدف الدراسة الحالية الى دراسة سلوك الاساسات السطحية بنوعيها (القواعد المنفصلة واساسات اللبشة) المنشأه على تربة قابلة للانتفاشية ومدي تأثرها بها وكذلك تأثير استخدام تربة احلال من الرمل النظيف والتربة المستخرجة من ناتج الحفر بعد معالجتها (باضافة ٢٠٪ من بودرة صخر الجير و٢٪ من مسحوق النانو سيليكا)على تقليل تأثير التربة الانتفاشية. ومن اجل تحقيق تلك الاهداف تم تمثيل مبنى مكون من ستة طوابق هذا المبنى ضمن مبانى فرع جامعة الازهر الجديد بمدينة الكوثر بمحافظة سوهاج وهو مقام على تربة عالية الانتفاش والتى تم عمل دراسة عليها لتعيين خواص الانتفاش لها.

خلصت الدراسة الى ان التأسيس على التربة القابلة للانتفاش بدون أستخدام تربة احلال تسبب زيادة عالية جدا فى قيم كلا من عزوم الانحناء والقوى المحورية لعناصر الاساسات المختلفة حيث بلغت الزيادة في قيم كلا من عزم الانحناء للقواعد المنفصلة الخارجية (القواعد الركنية) والشرائح الخارجية للبشة الى ١٠٠٪ و122% على التوالى من قيمها قبل حدوث الانتفاش. أثبتت الدراسة ايضا ان الميد هى أكثر عناصر الاساسات تأثرا بالتربة الانتفاشية حيث وصلت الزيادة في قيم كل من عزوم الانحناء للميد الخارجية الي ٣٠٠٪ من قيمها قبل الانتفاش.

استخدام تربة الاحلال من الرمل النظيف او التربة القابلة للانتفاش المعالجة يقلل من تأثير التربة الانتفاشية على الاساسات ويقل هذا التأثير بزيادة سمك الاحلال حيث وصل التخفيض فى قيم عزوم الانحناء للقواعد المنفصلة عند استخدام تربة احلال من الرمل والتربة المعالجة بسمك ٢,٢٥ متر ٧٥٪و٧٠٪ على التوالى والتخفيض فى عزوم الانحناء للميد وصل الى ١٠٠٪و ٨٣٪ على التوالى وكذلك التخفيض فى عزوم الانحناء للبشة وصل الى ٥٥,٣٣٪ و ٥٢٪ على التوالى وذلك من قيم العزوم عند التأسيس بدون استخدام تربة احلال . عند التأسيس على التربة القابلة للانتفاش يفضل استخدام نظام القواعد المنفصلة عن اللبشة لان تأثير التربة القابلة للانتفاش على القواعد المنفصلة اقل من تأثيرها على اللبشة وكذلك عند استخدام تربة الاحلال تكون مؤشرات التحسن فى سلوك القواعد المنفصلة أكبر من اللبشة.

الكلمات المفتاحية : التربة الانتفاشية , القواعد المنفصلة, الميد, الاساسات الحصيرة

1. INTRODUCTION

Expansive soils cover many areas in Egypt, especially new cities that have many new buildings under construction. The cycling of drying and wetting followed by swell and shrink of expansive soil results in the deformations and cracks that can be observed in the structures established in this soil. expansive soil characterized by hardness, high density, swell when subjected to wet or partial saturated, shrink due to low water content, a high Cation Exchange Capacity (CEC), a large specific surface area (SSA), and large clay content (Nalbantoglu and Gucbilmez, 2001[1], Nalbantoglu, 2004[2], Fityus and Buzzi, 2009[3] and Seco et al., 2011[4]). The stress history and suction affect the cycling of drying and wetting followed by swell and shrink of soil. (Zhang et al, 2016[5], Wang and Wei, 2015[6]; Singhal et al, 2015[7], Gens and Alonso, 1992[8]) resulting the deformations and cracks can be observed in the structures established at these soil (Yarbaşı and Kalkan, 2020[9], Selvakumar and Soundara, 2019[10].

Mostafa. and Mohamed. (2011) [11] used the PLAXIS 3D foundation software tool to simulate isolated footings supported by granular pile anchor foundations resting on expansive soil (GPAF). Their findings suggest that adopting a GPAF system to reduce vertical displacement, internal forces, and angular distortion induced by soil heave and shrinkage is a suitable foundation strategy.

Al-Busoda and Abbas. (2017) [12] modelled a communication tower with four legs and a height of 44 m built on expansive soil. The type of foundation employed was a raft on pile foundation. The goal of this research was to find a way to limit the uplift movement of a skyscraper built on expansive terrain. The major findings revealed that in order to achieve minimal uplift movement of a tower foundation built on expanding soil, the optimal ratio between the length of the pile (L) and its diameter (D) must be equal to 118, 113, and 102 for helical piles groups (2×2), (3×3) and (4×4) respectively.

Abdelmoneim et al. (2018) [13] investigated the impact of employing replacement soil under shallow foundations built on expansive soil on shallow foundation behaviour. A typical four-story building rests on Regina clay e expansive soil in the numerical model employed in this study. ABAQUS, a commercial software tool, was also used to conduct the numerical analysis. The major findings showed that employing replacement layer reduces heave along the building's centerline by 20%, 31%, and 40%, respectively, when using 1.0 m, 1.5 m, and 2.0 m depths replacement layer. the differential heave between the footings along the building's centerline drops by 25%, 31%, and 38%, respectively.
This paper presents a numerical model for a six-story residential building constructed on expansive soil, to study the effect of using replacement sand soil, and treating expansive soil on soil heave the induced moment and internal forces in the of isolated footing , ground beam , and mat foundation moment.

2. Numerical Model

The residential building in the university city of Al-Azhar University's new branch in Al-Kawthar city, Sohag government, was chosen to perform a numerical analysis on the influence of expansive soil, and the use of replacement sand soil and treatment expansive soil on the behaviour of shallow foundations. The building under study has six stories and is built on highly expansive soil.

The finite element model's were chosen (35*35*10m) to prevent any restriction or strain localization in the analysis. The investigated structure was considered to be a reinforced concrete structure with plan dimensions of (B=15* L=15 m) and six typical floors of 3.00 m height each. Each floor has three bays each with a width of 5.00 meters in each X and Y direction. In this investigation, the foundation level was set at -1.5 m below ground level. In this study, shallow foundations (isolated square footing and mat foundation) were used. The numerical geometry model for isolated footing (model1) and mat foundation (model2) are shown in **Fig. 1**. The flooring were assumed 0.20 m thick flat slabs fixed to columns with a 50 x 50 cm cross section. External columns are fixed on isolated footing (F1) with dimensions of 2.0*2.0*0.8 m, while interior columns are fixed on isolated footing (F2) with dimensions of 3.0*3.0*0.8 m as shown in **Fig.2**. For the numerical model, the footings were connected together with a ground beam with a section of (0.3*0.8m). The soil model used in the current study was with depth 10.0 m and consists from two soil layers:-

1- Layer No.1: The replacement sand soil with thickness 0.75m, 1.5m, and 2.25m. Expansive soil treated with 2% Nano-Silica and 20% Lime stone powder was also investigated as replacement layer.

2- .Layer No.2: Expansive clay soil continuous to the end of soil profile.

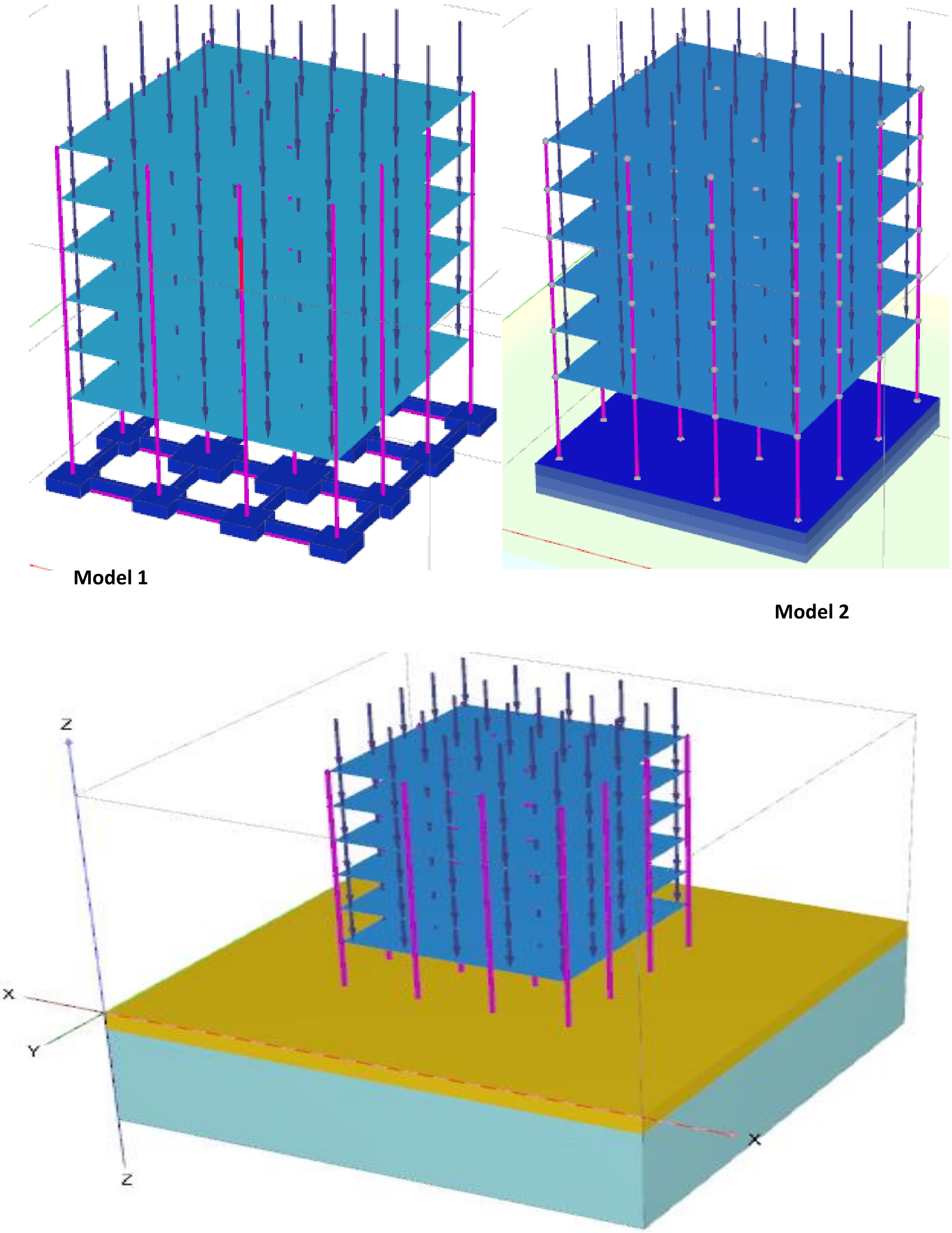

Fig. (1): finite element model geometry used in this analysis

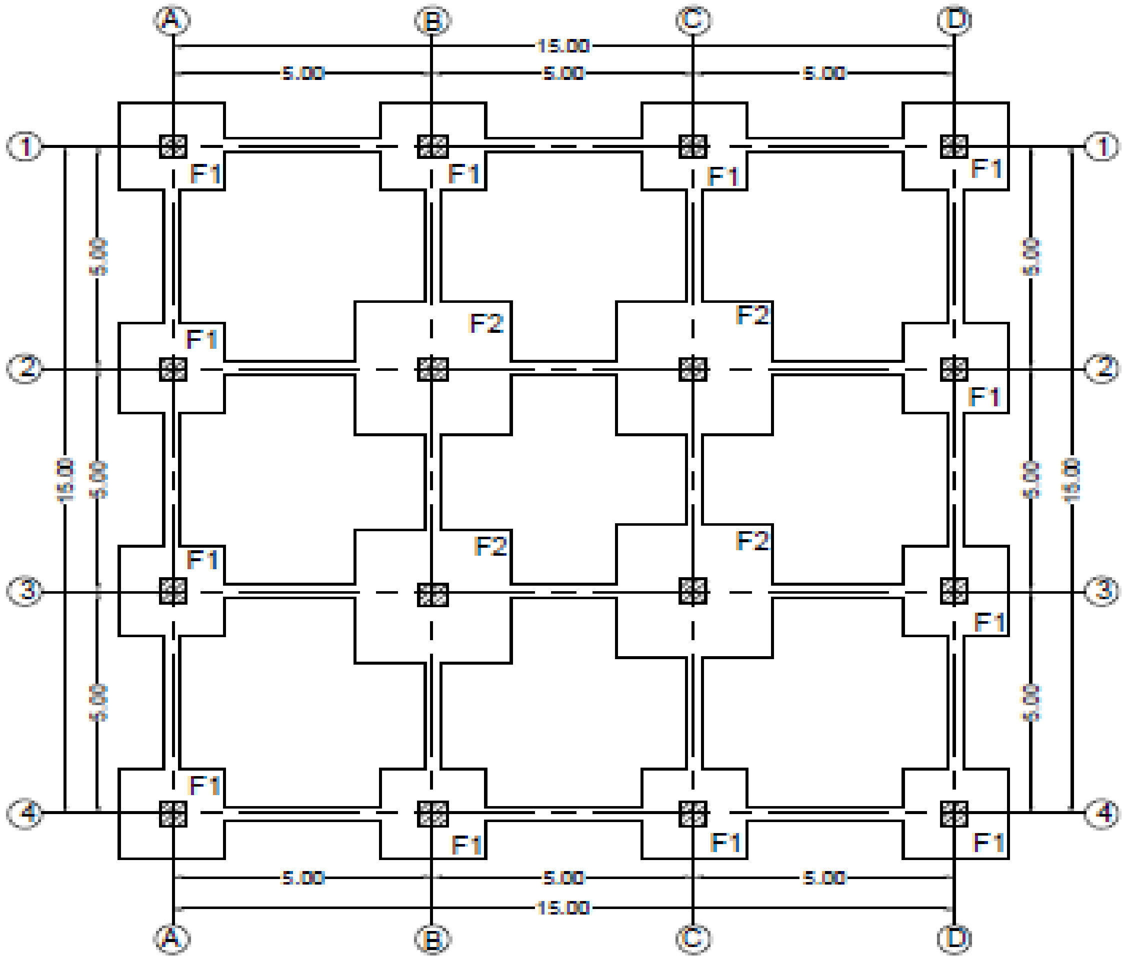

Fig. (2): plan view for the dimension of study structure and foundations models.

2.1. Matériel Model and Input Paramètres

Soil and construction materials are among the materials employed in the numerical model. Expansive clay soil, sand soil, and treated expansive soil are three types of soil material. Expansive soil data were determined from the tests that were conducted on samples extracted from the site of the new branch of Al-Azhar University in Al-Kawthar city – Sohag (Abd El-Samea, et al. 2021) [14]. Structure material includes the foundation material, ground beam material, column material, and flooring material. **Tables 1, 2 and 3** present the material qualities and input parameters for soil and construction materials.

The treated expansive soil was used under foundations as an alternative to sandy for cost-reduction. Excavation products from expansive soil are treated by adding 20% Lime stone powder and 2% Nano silica by the dry weight of the soil to reduce swelling potential and swelling pressure (Abd El-Samea, et al. 2021) [14]. The treated soil was compacted to reach its maximum dry density (1.67 t/m^3) and optimum water content (11.34%).

Table 1: Input physical and mechanical properties of expansive clay soil

Parameter	Expansive clay soil	Sandy soil	Treatment expansive soil
Model Type	Mohr-Coulomb	Mohr Coulomb	Mohr-Coulomb
Type of material behavior	Drained	Drained	Drained
Unsaturated unit weight, γ_{unsat} (kN/m^3)	21.7	18.6	19
Saturated unit weight, γ_{sat} (kN/m^3)	23	21	20.05
Void ratio e	0.37	0.5	0.66
E (kN/m^2)	7500	10^5	7500
E_{oed} (kN/m^2)	10100	$1.35*10^5$	10100
Poisson's ratio, υ	0.3	0.3	0.3
Drained cohesion, c_u (kN/m^2)	50	0	٥٥
Friction angle, φ	30º	37º	32º
Dilatancy angle, ψ	0	7º	0

Table 2: Floor and foundation parameters used in numerical study.

Parameter	Unites	Floor	Foundation
Material Type	――――――	Elastic	Elastic
Floor thickness	m	0.20	0.80
unit weight, γ	(kN/m³)	24	24
Modula's of elasticity E	(KN/m²)	$2.2 *10^6$	$2.2 *10^6$
Poisson's ratio, υ	――――――	0.2	0.2
Shear modules G	(kN/m²)	$9.16 *10^5$	$9.16 *10^5$

Table 3: Column and ground beam parameters used in numerical study

Parameter	Unites	Column	Ground beam
Material Type	――――――	Elastic	Elastic
unit weight, γ	(kN/m³)	24	24
Modula's of elasticity E	(KN/m²)	$2.2 *10^6$	$2.2 *10^6$
Poisson's ratio, υ	――――――	0.2	0.2
Cross section A	m^2	0.25	0.24
Moment of inertia I	m^4	$5.2 *10^{-3}$	$5.2 *10^{-3}$

2.2. Mesh Generation

The number of 15-node triangular elements and the average element size are determined by the global coarseness's setting. To display a more accurate stress distribution, a simple global finite element mesh of the model is created. Mesh was set to the medium setting.

2.3 Loads Applied in Numerical Model

There are two types of loads acting on the floor of the structure:

1. Vertical Dead load which results from dead load of slab, floor cover and wall and are equal to ((25*0.2) + 1.5+1.5 = 8 kPa
2. Vertical live load, which results from live load of structure and is equal to 5 kPa. (Egyptian code ECP 205 – 2001) [15].

Total surface load applied on floors in (Z ↓) direction equal to 13 kPa

In general, these loads and the weight of the foundation are considered a light weight which cannot resist the uplift movement of expansive soil when swelling takes place. Therefore, it is important to use replacement soil to reduce upward movement.

2.3. Calculation Stages

The actual finite element calculations can be performed after the finite element modelling of the given problems is completed. For finite element calculations, three stages are chosen for this type of issue. Construction of the superstructure and foundation is the first stage (no swell stage). Plat elements, beam elements, and surface loads are triggered in the initial step.

The second stage (no replacement stag) uses the expansive clay soil's swelling capacity. The positive volumetric strain is activated in the expansive clay soil cluster in the second step. The third stage involves employing replacement sand soil and treatment soil with thickness 0.75m, 1.5m, and 2.25m. Cases solved in numerical study are presented in **Table 4**.

The heave and shrinkage events were independently applied of each other, starting from the stage after the application of the dead and live loads (Mostafa and Mohamed. 2011). [16]. The swelling of the expansive soil layer is modelled by applying positive volumetric strain of 26.4% and 4.5% to the expansive soil cluster and treatment expansive soil, respectively. This value of volumetric strain was obtained previously from the average value of swelling under stress equal to 2.0 kg/cm^2 (average stress resulting from building loads) for undisturbed expansive soil samples used. In reality, the rate at which expansive soil would normally swell depends on the position of the source of moisture and the magnitude of overburden effective pressure. However, for simplification, in the analyses presented herein, the volumetric strain was uniformly applied across the full depth of the expansive soil layer. (Al-Busoda and Abbas (2017)) [17].

3. Results and Discussion

An additional independent analysis was carried out for the structure resting on isolated footings and mat foundation without and with replacement of sandy soil and treatment expansive soil, to investigate the influence of using replacement soil on the behaviour of a shallow foundation placed over expansive soil.

3.1. Effect of Replacement Soil Thickness on the Behavior of Shallow Foundation

The effect of the replacement soil layer thickness on soil heave percent, isolated footing bending moment, ground beam internal force, and mat foundation bending moment is discussed in the following section.

Table 4: Cases solved in numerical study

Foundation system	**Replacement soil type**	**Replacement soil thickness (m)**	**Case No**
Isolated footing	Replacement medium sand soil	0	1
		0.75	2
		1.50	3
		2.25	4
	Replacement treatment expansive soil	0.75	5
		1.50	6
		2.25	7
Mat foundation	Replacement medium sand soil	0	8
		0.75	9
		1.50	10
		2.25	11
	Replacement treatment expansive soil	0.75	12
		1.50	13
		2.25	14

3.1.1 Soil Heave under footing

Fig 3. Shows the effect of increasing in the replacement soil layer thickness on soil heave under corner footing, side footing and middle footing. It is observe that, soil heave decreased by increasing replacement soil thickness depending on reducing expansive soil depth.

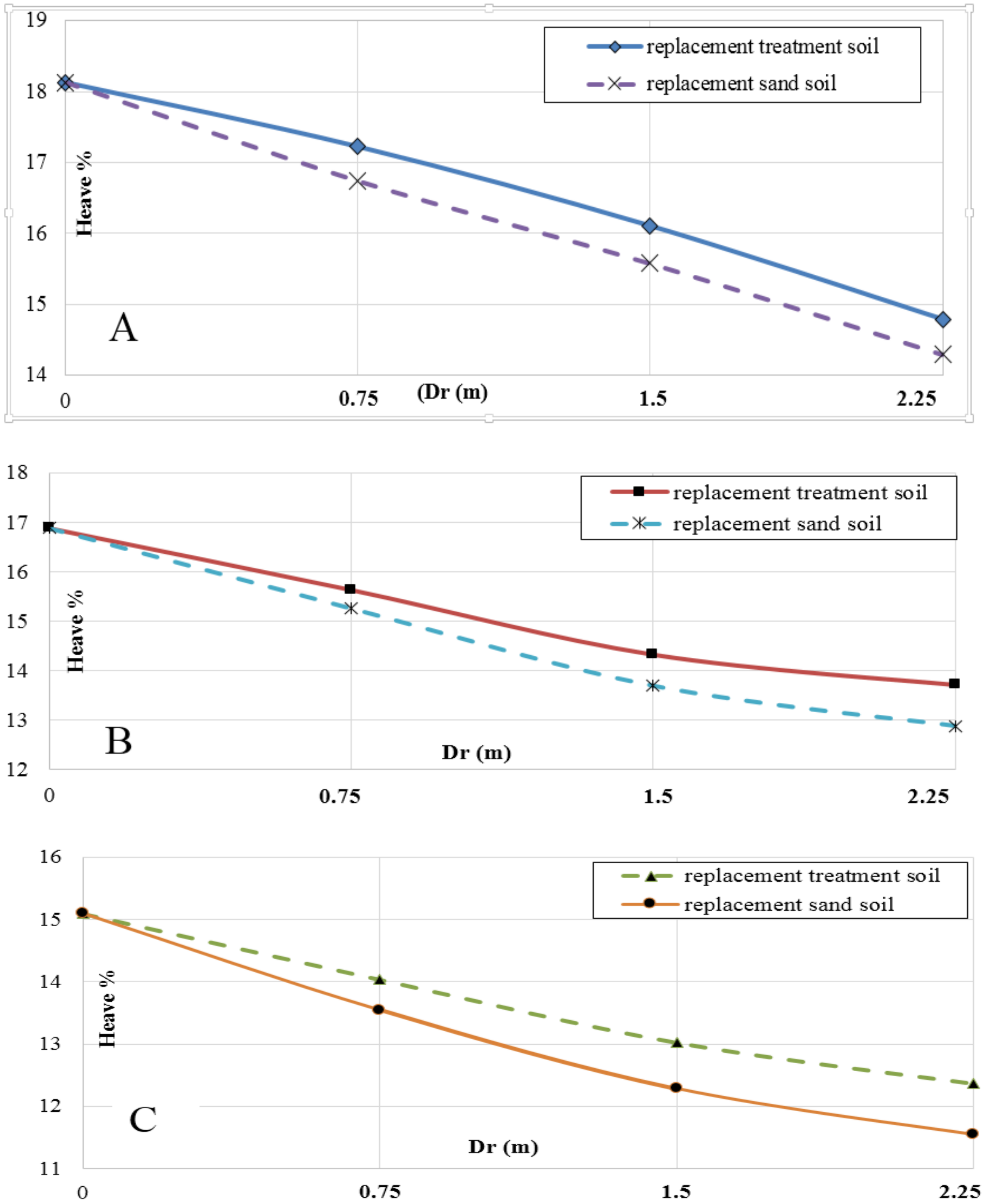

Fig. (3): Effect of replacement soil thickness on soil heave under

A- Corner footing. B- Side footing. C- Middle footing

From the shown figures, it can concluded that increasing in replacement soil layer thickness decreased soil heave. The reduction in soil heave under footings are concluded in Table (5).

Table (5): The reduction in soil heave under Corner footing, Side footing, and Middle footing

Replacement soil type	Replacement soil thickness (m)	Reduction in soil heave (%)		
		Corner footing	Side footing	Middle footing
Sandy soil	0.75	7.65	9.6	10.28
	1.5	14.08	18.87	18.62
	2.25	21.15	23.68	23.53
Treatment soil	0.75	5	7.37	7
	1.5	11.16	15.11	13.72
	2.25	18.43	18.73	18

3.1.2 Footing Moment

For corner footing, side footing, and middle footing, **Fig 4** shows the relationship between the percentage increase in the footing moment and the thickness of the replacement soil layer. It is observed that swelling action and the replacement soil thickness have a significant effect on footing moment. Because the vertical load on the corner footing is less than that on the side and middle footing, it is more impacted by swelling action and the replacement soil layer thickness than the side and middle footings. Swelling of expansive soil causes an increase in footing moment by 100%, 78.23% and 25.28% for corner, side, and middle footings, respectively, without using replacement soil. Replacement soil decreased the effect of swelling soil on footing moment, but it does not restore it to its pre-swelling value.

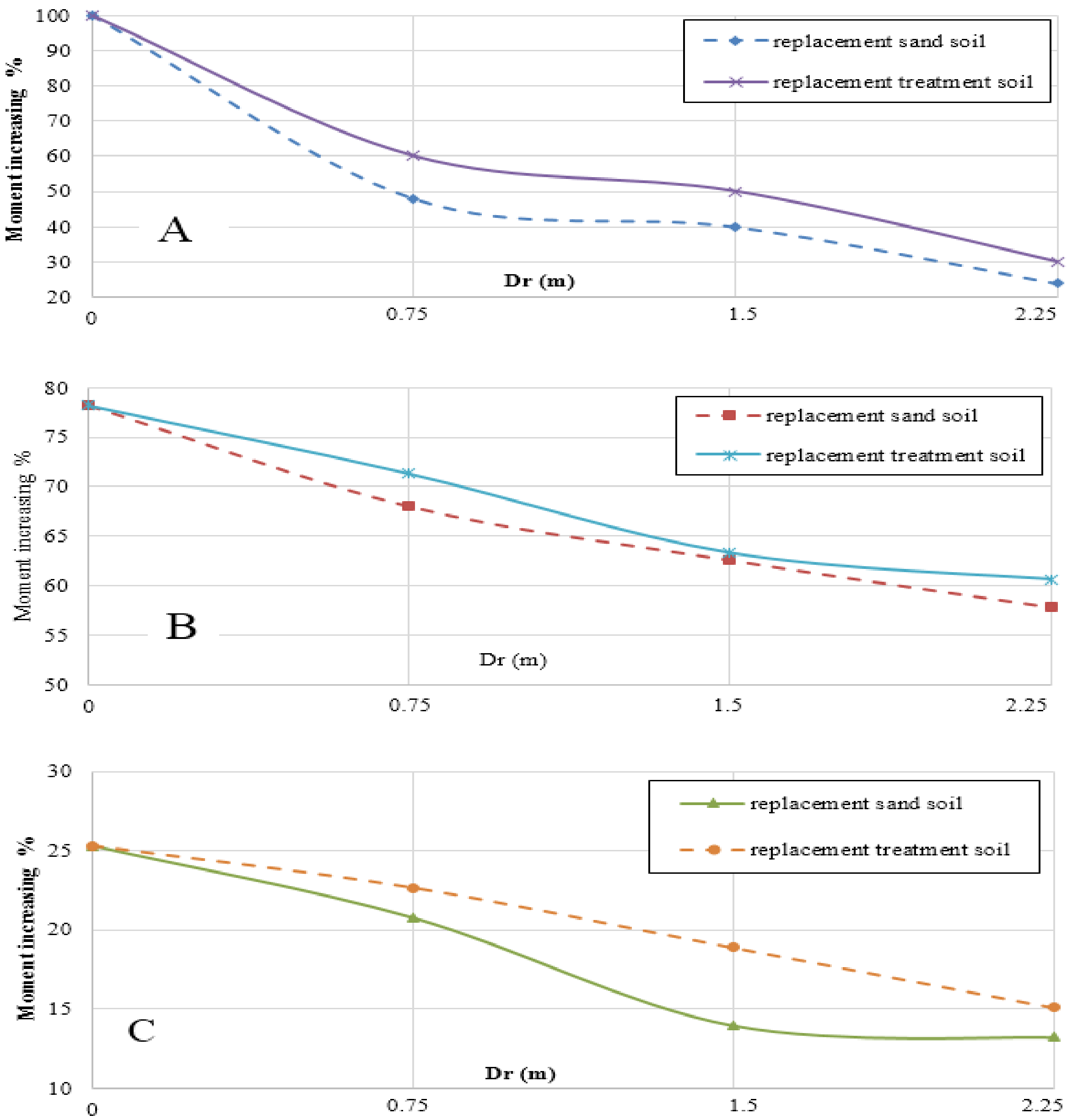

Fig. (4): Relationship between replacement soil thickness and increasing in footing moment for

A-corner footing B-side footing C-middle footing

3.1.3 Ground Beams Internal Forces

Ground beam foundation elements are more affected by expansive soil than other foundation elements because they resist the increased differential displacement between the footings caused by soil heave. **Figs. 5** and **6** show the influence of replacement soil layer thickness on the maximum value of moment and normal force for external and internal ground beams, respectively.

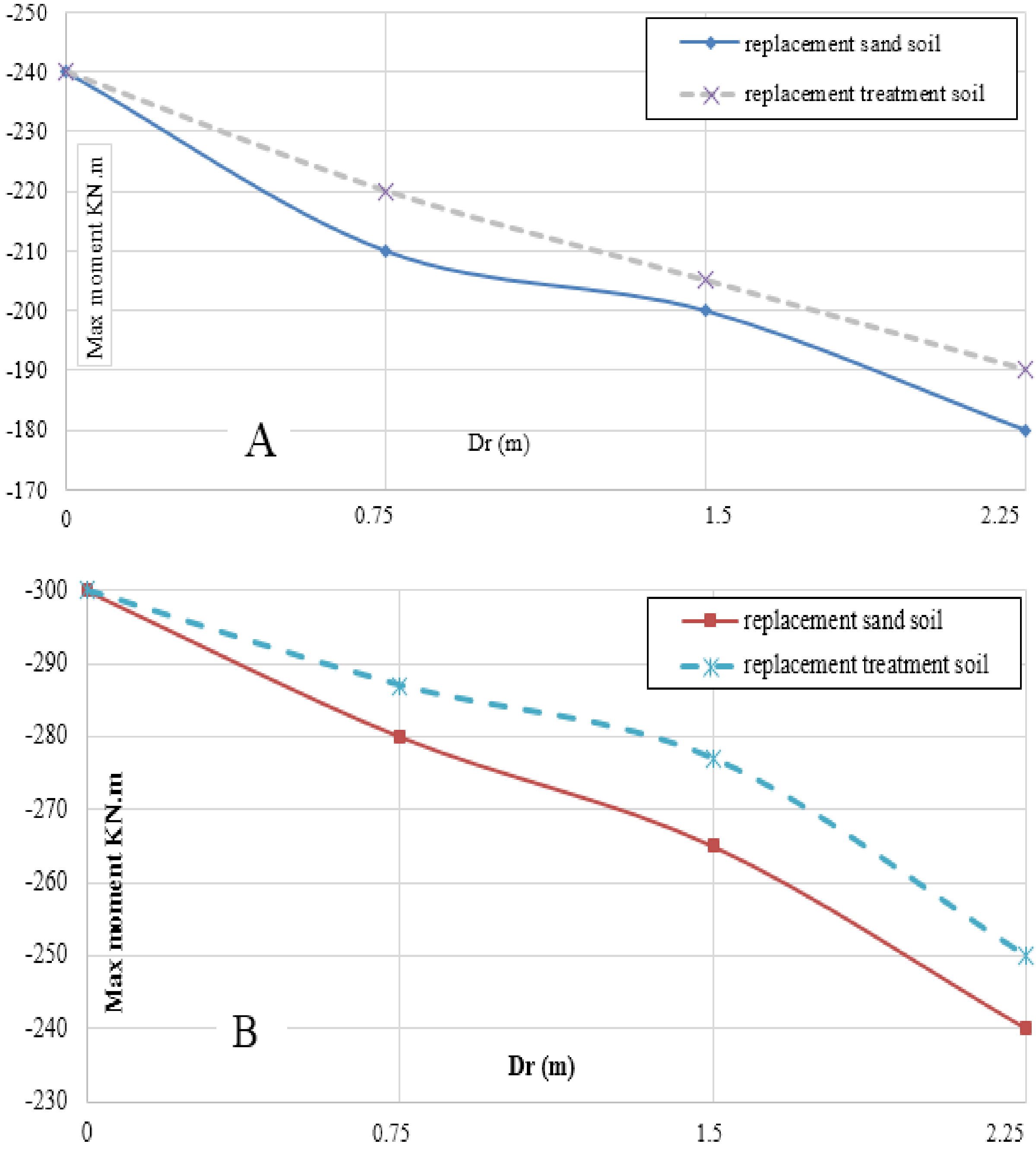

Fig. (5): Relationship between replacement soil thickness and maximum value of ground beam moment for

A-External ground beam B-Internal ground beam

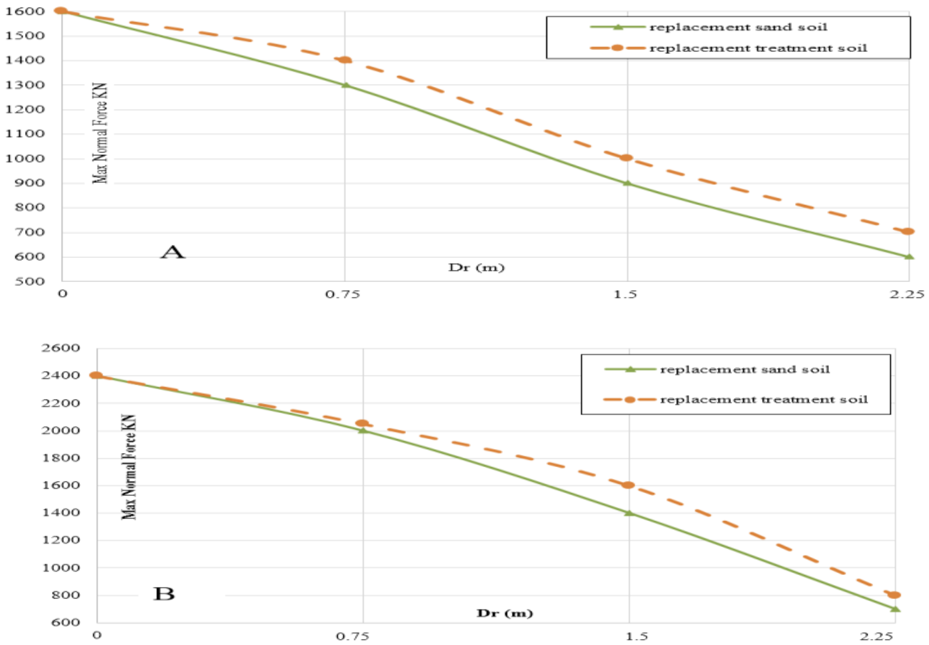

Fig. (6): Relationship between replacement soil thickness and maximum value of ground beam Normal force for A-External ground beam B-Internal ground beam

From the previous figures, it can be observed that expansive soil generates a significant increase in the maximum value of ground beam moment and normal force, as indicated in the figures. Although the influence of expansive soils on ground beams is reduced when replacement soil is used, there is still a significant increase in the value of moment and normal force that must be considered when designing ground beams.

The increase in ground beam internal forces due to swelling decreases by increasing the replacement soil thickness for both sand soil and the treatment expansive soil. There was no noticeable change in ground beam internal forces in the case of using treated expansive soil or sand soil in the replacement soil layer under foundations.

Expansive soil causes a great increase in the maximum value of ground beam moment and normal force. The increasing in ground beam internal forces (as ratio from its value before swelling) du to soil heave in cases without and with using replacement soil are concluded in Table (6).

Table (6): The increasing in ground beam internal forces du to soil heave.

Replacement soil type	Replacement soil thickness (m)	Internal forces increasing (%)	
		Maximum Bending moment	Maximum Normal force
Sandy soil	0	300	600
	0.75	250	350
	1.5	233.33	250
	2.25	200	100

3.1.4 Soil Heave under Mat Foundation

Fig. 7 depicts the relationship between average soil heave percent and replacement soil thickness along the mat foundation exterior and internal field strips. Because of the decline in expansive soil thickness, soil heave diminishes with increasing replacement sand soil thickness.

From figure (7), we can observe that, using replacement soil under the mat foundation doesn't give a noticeable change in soil heave. Increases in replacement soil thickness of 5%, 10%, and 15% of foundation width decreased average values of soil heave by 9.74%, 13.13%, and 13.24%, respectively, along exterior field strips and by 9.16%, 12.81%, and 13.56%, respectively, along interior field strips of mat foundation.

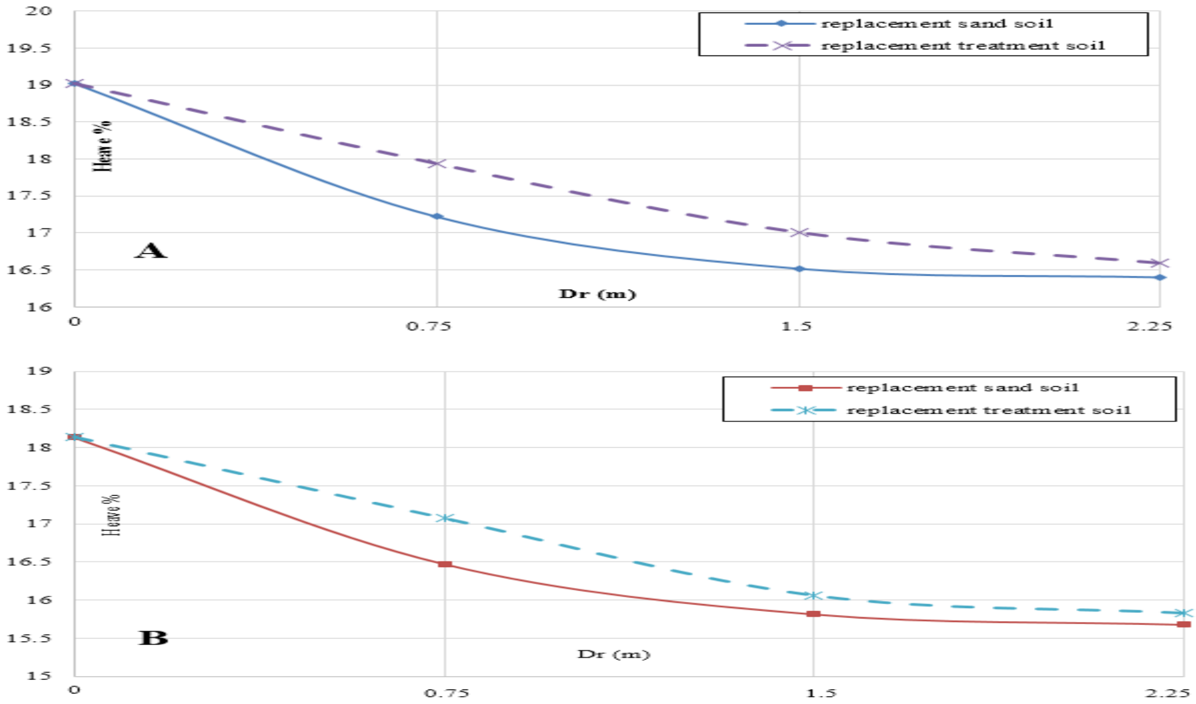

Fig. (7): The relationship between average values of soil heave percent for mat foundation and the replacement soil thickness along A- External field strips B-Internal field strips

3.1.5 Mat Foundation Moment

For mat foundation, **Fig. 8** shows the increase in maximum moment value along external column stripes, internal column strips, and internal field strips.

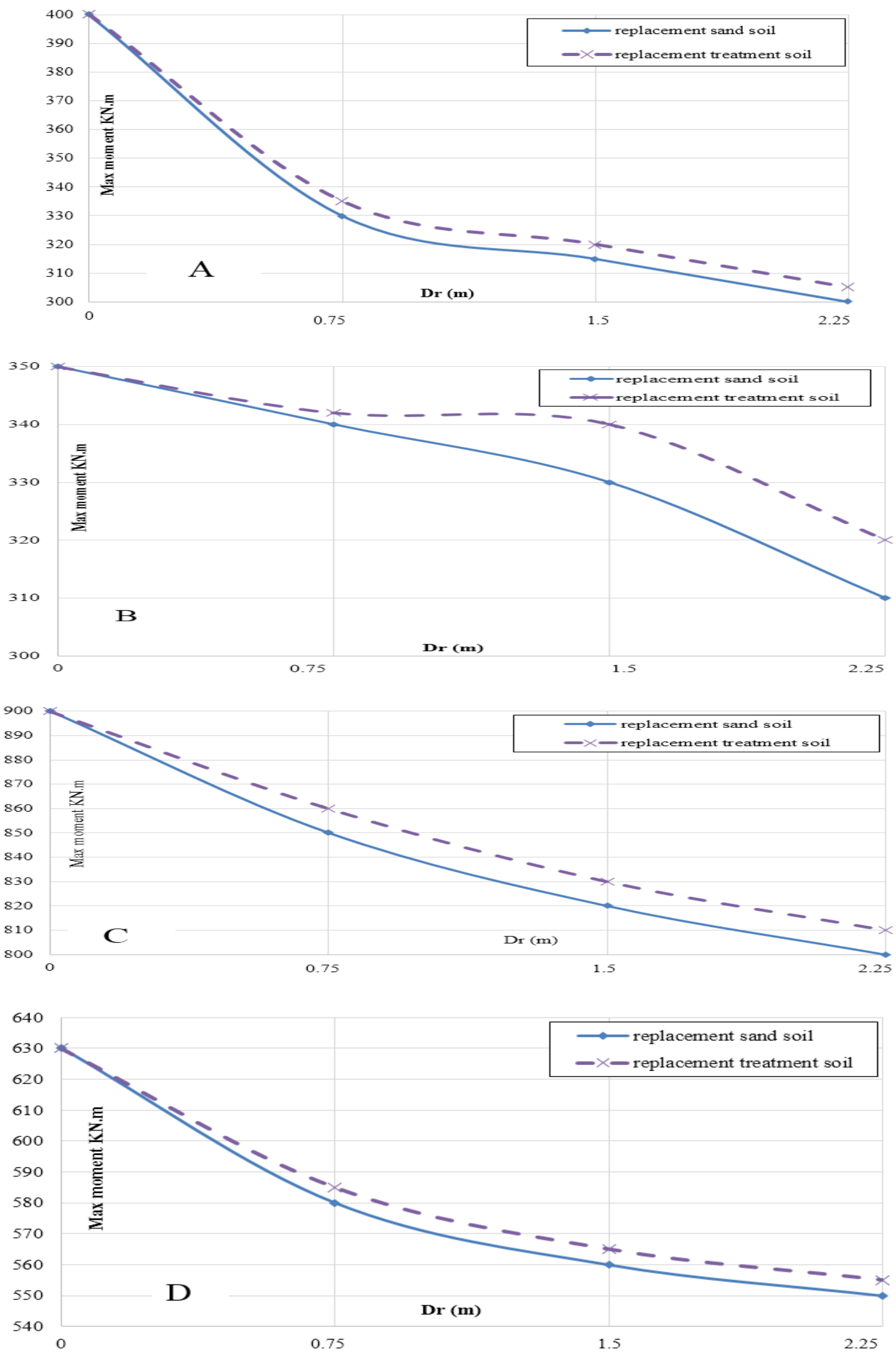

Fig. (8): Effect of replacement soil thickness on the maximum value of mat foundation moment along A- External column strips B- External field strips C- Internal column strip D- Internal field strips.

Expansive soil causes a large increase in the maximum value of moments along field strips rather than the maximum value of moments along column strips, as shown in the figures, because vertical stress from structure load on column stripes is greater than that on field strips, making column strips more resistant to soil heave than field strips. The influence of expansive soils on mat foundations is reduced when replacement soil is used, but there is still a significant increase in the value of moments along field strips that must be considered when designing the mat foundation. The expansive soil has a greater impact on the mat foundations' external strips than on their inside strips. Increasing replacement soil thickness reduces the increase in mat foundation moment due to swelling. The maximum value of moment along the external column strip, internal column strip, external field strip, and internal field strip of the mat foundation increased by 122.22%, 125%, 337.5%, and 600%, respectively, in the case of a constructed mat foundation directly over expansive soil without using replacement soil.

3.2 Effect of Foundation System on the Behavior of the Foundation over Expansive Soil

For mat foundation systems and isolated foundation systems, **Fig. 9 and Fig. 10** show the effect of changing the thickness of the replacement soil layer on the average value of soil heave under the foundation and bending moment, respectively. As can be seen in the diagram, decreasing average values of soil heave percent and foundation moment due to increasing replacement soil thickness in case of an isolated foundation system is greater than in the case of a mat foundation system, because the space between the isolated footings helps to partially dissipate the heave of swelling soils, while the mat foundation miss this function, so we recommend isolated foundations when establishing on expansive soil.

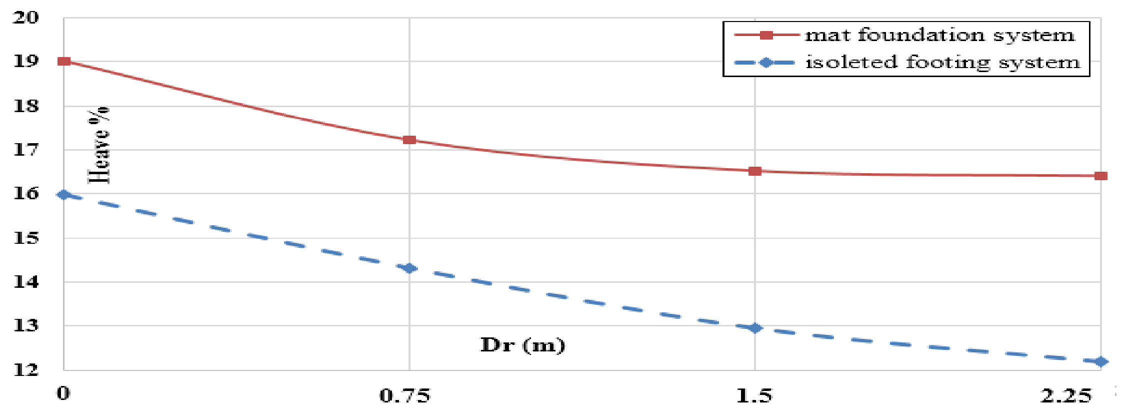

Fig. (9): The change in average value of soil heave percent due to change in thickness of the replacement sand soil for mat foundation system and isolated foundation system.

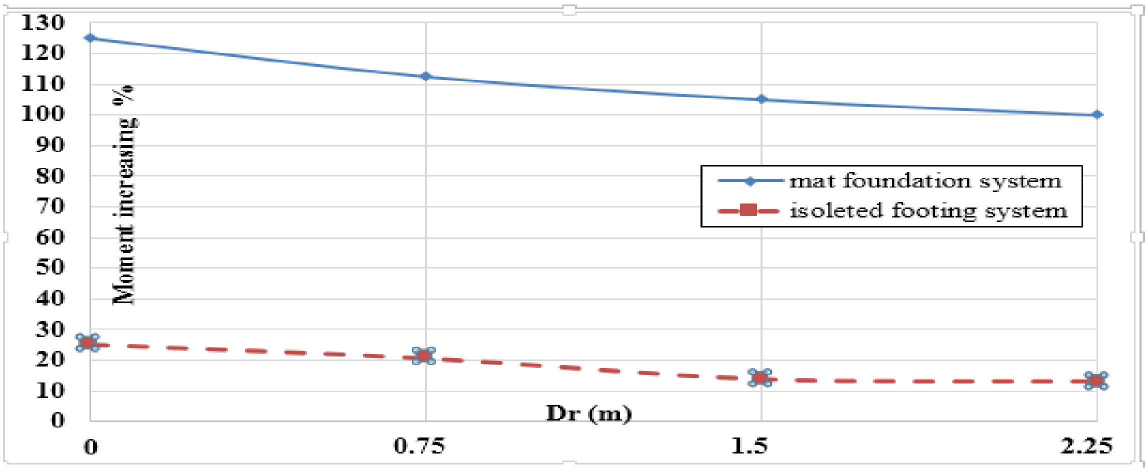

Fig. (10): The effect of change in replacement soil thickness on the maximum value of foundation moment for mat foundation system and isolated footing system.

3.2 Effect of Expansive Soil and Replacement Soil on the Concrete Section and reinforcement of Shallow Foundation Elements

Tables 7, 8,9 and 10 show the change in concrete sections and reinforcement for isolated footing, ground beam, and mat foundation in the case of non-swelling, swelling without using replacement soil, swelling with the use of sand soil, and swelling with expansive soil in the replacement soil layer with a thickness of 5%, 10%, and 15% of the foundation width.

Table 7: Various concrete section and reinforcement for isolated footing constructed on expansive soil in cases of without and with using replacement soil.

Footing position	Replacement soil type	Dr (m)	Max moment KN.M	Footing depth (cm)	Footing reinforcement
Corner Footings	Non-swelling		50	40	7Φ12/m
	Without using replacement soil		100	50	10Φ12/m
	Medium sand soil	0.75	74	45	9Φ12/m
		1.5	70	45	8Φ12/m
		2.25	62	40	8Φ12/m
	Treatment expansive soil	0.75	80	45	9Φ12/m
		1.5	75	45	9Φ12/m
		2.25	65	40	9Φ12/m
Side Footings	Non-swelling		150	60	7Φ16/m
	Without using replacement soil		265	80	9Φ16/m
	Medium sand soil	0.75	250	75	9Φ16/m
		1.5	242	70	9Φ16/m
		2.25	235	70	9Φ16/m
	Treatment expansive soil	0.75	257	75	9Φ16/m
		1.5	245	70	9Φ16/m
		2.25	241	70	9Φ16/m[MB١] [MB٢][MB٣]
Middle Footings	Non-swelling		265	٨٠	9Φ16/m
	Without using replacement soil		332	90	10Φ16/m
	Medium sand soil	0.75	320	90	10Φ16/m
		1.5	302	85	10Φ16/m
		2.25	300	85	10Φ16/m
	Treatment expansive soil	0.75	325	90	10Φ16/m
		1.5	315	85	10Φ16/m
		2.25	305	85	10Φ16/m

Table 8: Various concrete section and reinforcement for ground beam constructed on expansive soil

Ground beam position	Replacement soil type	D_r (m)	M_{max} KN.m	N_{max} KN	Ground beam section (cm)	Reinforcement Bottom	Reinforcement Top
Side Ground beam	Non-swelling		-60	200	30*60	3Φ16	5Φ18
	Without using replacement soil		-240	1600	30*120	9Φ22	16Φ22
	Medium sand soil	0.75	-210	1300	30*115	7Φ22	13Φ22
		1.5	-200	900	30*110	4Φ22	10Φ22
		2.25	-180	600	30*110	3Φ18	8Φ22
	Treatment expansive soil	0.75	-220	1400	30*115	8Φ22	14Φ22
		1.5	-205	1000	30*110	5Φ22	11Φ22
		2.25	-190	700	30*110	3Φ22	8Φ22
Middle Ground beam	Non-swelling		-80	240	30*70	3Φ16	5Φ18
	Without using replacement soil		-300	2400	30*135	15Φ22	22Φ22
	Medium sand soil	0.75	-280	2000	30*130	12Φ22	19Φ22
		1.5	-265	1400	30*125	7Φ22	14Φ22
		2.25	-240	700	30*120	3Φ18	9Φ22
	Treatment expansive soil	0.75	-287	2050	30*130	12Φ22	19Φ22
		1.5	-277	1600	30*130	9Φ22	15Φ22
		2.25	-250	800	30*125	4Φ18	9Φ22

Table 9: Various concrete section and reinforcement for mat foundation constructed on expansive soil in cases of without and with using replacement soil for external column and field strip.

Strip position	Replacement soil type	D_r (m)	M_{max} KN.M	Mat foundation depth (cm)	Mat foundation reinforcement	
					Bottom	Top
External Column strip	Non-swelling		180	90	6Φ16/m	As min
	Without using replacement soil		400	130	9Φ16/m	
	Medium sand soil	0.75	330	130	7Φ16/m	
		1.5	315	130	7Φ16/m	
		2.25	300	120	7Φ16/m	
	Treatment expansive soil	0.75	335	130	7Φ16/m	
		1.5	320	130	7Φ16/m	
		2.25	305	130	7Φ16/m	
External Field strip	Non-swelling		-80	90	As min	6Φ16/m
	Without using replacement soil		350	130		9Φ16/m
	Medium sand soil	0.75	340	130		7Φ16/m
		1.5	330	130		7Φ16/m
		2.25	310	120		7Φ16/m
	Treatment expansive soil	0.75	342	130		7Φ16/m
		1.5	340	130		7Φ16/m
		2.25	320	130		7Φ16/m

Table 10: Various concrete section and reinforcement for mat foundation constructed on expansive soil in cases of without and with using replacement soil for internal column and field strip.

Internal Column strip	Non-swelling		400	90	8Φ22/m	As min
	Without using replacement soil		900	130	12Φ22/m	
	Medium sand soil	0.75	850	130	11Φ22/m	
		1.5	820	130	11Φ22/m	
		2.25	800	120	11Φ22/m	
	Treatment expansive soil	0.75	860	130	11Φ22/m	
		1.5	830	130	11Φ22/m	
		2.25	810	130	11Φ22/m	
Internal Field strip	Non-swelling		-90	90	As min	6Φ16/m
	Without using replacement soil		630	130		11Φ18/m
	Medium sand soil	0.75	580	130		10Φ18/m
		1.5	560	130		10Φ18/m
		2.25	550	120		10Φ18/m
	Treatment expansive soil	0.75	585	130		10Φ18/m
		1.5	565	130		9Φ18/m
		2.25	555	130		9Φ18/m

SUMMARY AND CONCLUSIONS

This numerical study aims at enhancing the behavior of shallow foundation over expansive soil in order to improve its durability, decreases foundation deformation and increase safety factors. Based on the numerical results and the above discussions, the following conclusions can be derived:

1) Soil heave decreased by increasing replacement soil layer thickness depending on reducing expansive soil depth. Using replacement soil with thickness 0.75m, 1.50m, and 2.25m decreased soil heave by 7.65%, 14.08% and 21.15% respectively for corner footing and by 9.6%, 18.87% and 23.68% respectively for side footing and by 10.28%, 18.62%, and 23.53% respectively For middle footing.

2) Swelling of expansive soil causes an increase in footing moment by 100%, 78.23% and 25.28% for corner footing, side footing, and middle footing, respectively, without using replacement soil. Replacement soil lowers the effect of swelling soil on footing moment, but it does not restore it to its pre-swelling value.

3) Expansive soil causes a great increase the ground beam moment and normal force. Maximum moment increased by 300%, 250%, 233.33%, and 200% when replacement soil with thicknesses 0.75m, 1.50m, and 2.25m was used, respectively. Maximum normal force increased by 600%, 350%, 250%, and 100% when replacement soil with thicknesses 0.75m, 1.50m, and 2.25m was used, respectively.

4) Using replacement soil with thickness 0.75m, 1.50m, and 2.25m decreased soil heave by 9.44%, 13.133%, and 13.73%, respectively, along the external field strip and decreased by 9.16%, 12.81%, and 13.56%, respectively, along the internal field strip of the mat foundation.
5) The maximum value of moment along the external column strip, internal column strip, external field strip, and internal field strip of the mat foundation increased by 122.22%, 125%, 337.5%, and 600%, respectively, in the case of mat foundation directly over expansive soil without replacement soil.
6) Using replacement soil reduces the effect of expansive soils on mat foundation, but there is still a significant increase in the value of moment along field strips that must be taken into account when designing the mat foundation.
7) There is no noticeable change in soil heave under the foundation and internal force of foundation elements in the case of using treated expansive soil or sand soil in the replacement soil layer under the foundations.
8) The decrease in average value of soil heave percent and foundation moment due to the increase in thickness of the replacement soil layer in the case of using an isolated foundation system is greater than that in the case of using a mat foundation system. Therefore, we recommend the use of isolated foundations when establishing on expansive soil.
9) When establishing on expansive soil, concrete sections and foundation element reinforcement must be increased.

ACKNOWLEDGMENTS

The authors wish to acknowledge the support of Prof. Dr. Mamdouh Abbas Kenawy, Head of the Civil Engineering Department, and all employees of the soil mechanics lab at the Faculty of Engineering, Sohag University, for providing the apparatus and tools used in determining the expansive clay and sandy soil properties used in the present paper.

REFERENCES

1. Nalbantoglu, Z., Gucbilmez, E., 2001. Improvement of calcareous expansive soils in semi-arid environments. Journal of Arid Environments 47 (4), 453-463.
2. Nalbantoglu, Z., 2004. Effectiveness of Class C fly ash as an expansive soil stabilizer. Construction and Building Materials 18 (6), 377-381.
3. Fityus, S., Buzzi, O., 2009. The place of expansive clays in the framework of unsaturated soil mechanics. Applied Clay Science 43 (2), 150–155.
4. Seco, A., Ramírez, F., Miqueleiz, L, García, B, 2011. Stabilization of expansive soils for use in construction. Applied Clay Science 51, 348-352.
5. Zhang, J., Sun, D., Zhou, A., Jiang, T., 2016. Hydro mechanical behavior of expansive soils with different suctions and suction histories. Canadian Geotechnical Journal 53(1),1-13.
6. Wang, G., Wei, X., 2015. Modeling swelling–shrinkage behavior of compacted expansive soils during wetting-drying cycles.Canadian Geotechnical Journal 52 (6), 783-794.
7. Singhal, S., Houston, S.L., Houston, W.N., 2015. Swell pressure, matric suction, and matric suction equivalent for undisturbed expansive clays. Canadian Geotechnical Journal 52 (3), 356–366
8. Gens, A., Alonso, E.E., 1992. A framework for the behavior of unsaturated expansive clays. Canadian Geotechnical Journal 29(6), 1013-1032.
9. Yarbaşı, N., Kalkan, E., 2020. The Mechanical Performance of Clayey Soils Reinforced with Waste

PET Fibers. International Journal of Earth Sciences Knowledge and Applications 2 (1), 19-26.

10. Selvakumar, S., Soundara, B., 2019. Swelling behaviour of expansive soils with recycled geofoam granules column inclusion. Geotextiles and Geomembranes 47, 1-11.
11. Mostafa A.I. and Mohamed A.S. 2011. Finite element modeling of innovative shallow foundation system for reactive soils. Int. J. of GEOMAT, Oct. 2011, Vol. 1, No. 1 (Sl. No. 1), pp., 78-82 Geotec., Const. Mat. and Env., ISSN: 2186-2982(p), 2186-2990(O), Japan.
12. Al-Busoda, B. S., & Abbas, H. O. (2017). Numerical Simulation of Mitigation of Soil Swelling Problem under Communication Tower Using Helical Piles. Journal of Geotechnical Engineering (JoGE), 4(3).
13. Abdelmoneim D, El-Taher M, Akl S.A, and Mamlouk. H.H. (2018). Analysis of replacement layer properties and its effects on a typical building on swelling clay. Cairo University, Faculty of Engineering, Public Works Department, Egypt Suez canal University, Egypt.
14. Waleed H. Abd El-Samea, Yousry M. Mowafy, Mostafa A. Abd El- Naiem and Ahmed R. Towfeek (2021). Treatment of expansive soils using Nano silica and rock powder. Al-Azhar Engineering Fifteenth International Conference 2021.
15. ECP202 – 2001, Edition - 2009. Egyptian Code of Soil Mechanics and Foundations, (2009) part No. 3 & 5.
16. Mostafa A.I. and Mohamed A.S. (2011). Finite element modeling of innovative shallow foundation system for reactive soils. Int. J. of GEOMAT, Oct. 2011, Vol. 1, No. 1 (Sl. No. 1), pp., 78-82 Geotec., Const. Mat. and Env., ISSN: 2186-2982(p), 2186-2990(O), Japan.
17. Kaliakin, V.N. (2017). Soil Mechanics: calculations, principles, and methods. Butterworth-Heinemann, an imprint of Elsevier, Kidlington, Oxford Cambridge.