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STUDY THE BEHAVIOUR OF EXPANSIVE SOIL USING FINITE ELEMENT ANALYSIS

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ABSTRACT

Expansive soil is considered one of the most important causes of the collapse of buildings and facilities. There are many factors affecting the stability of structures constructed on expansive soils. In this paper, the numerical analysis using Plaxis 3D commercial software v.24 was carried out on the swelling soil obtained from Al-Azhar university branch, Sohage government in Upper Egypt. Also, a parametric study was carried out to study the effect of some parameters like: the type of replacement, the thickness of replacement, and the ground water rise. It was found that using a replacement layer of sand only gives lower bending moment and shear force values than using replacement layers consisting of sand and gravel. Also, the maximum bending moment and shear force decreased as the ratio D/B increased. Moreover, the effect of groundwater level disappeared when the ratio D/B was greater than 3.0. Finally, Using sand as a replacement layer under foundations constructed on expansive soil dissipated the effect of the change in groundwater level.

KEYWORDS: Expansive soils, Numerical analysis, Ground water level, Replacement layers, Swelling Pressure

دراسة سلوك التربة الانتفاشية باستخدام تحليل العناصر المحدودة

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الملخص

تعتبر التربة الانتفاشية من أهم أسباب انهيار المباني والمنشآت، وهناك العديد من العوامل التي تؤثر على استقرار المنشآت المقامة على هذه التربة. في هذا البحث تم إجراء تحليل العناصر المحدودة للتربة الانتفاشية من خلال برنامج بلاكسس اصدار 24 وذلك على تربة مأخوذة من فرع جامعة الأزهر فى محافظة سوهاج، كما تم إجراء دراسة بارامترية لدراسة تأثير بعض العوامل مثل: نوع طبقات الاحلال، وسمك طبقات الاحلال ، وارتفاع المياه الجوفية. وقد وجد أن استخدام طبقة احلال من الرمل فقط يعطي قيم أقل لعزم الانحناء وقوة القص من استخدام طبقات احلال مكونة من الرمل والزلط معا. أيضا كلما انخفض منسوب المياه الجوفية انخفضت قيم عزوم الانحناء وقوى القص . علاوة على ذلك فإن سمك طبقات الاحلال يؤثر بشكل كبير على قيم عزوم الانحناء وقوى القص . وأخيرا، فإن استخدام الرمل كطبقة احلال

تحت الأساسات المنشأة على تربة انتفاشية أدى إلى انعدام تأثير التغير في منسوب المياه الجوفية.

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الكلمات المفتاحية : التربة الانتفاشية , التحليل العددى , منسوب المياه الجوفية , طبقات الاحلال , ضغط الانتفاخ

1. INTRODUCTION

Expansive soil characterized by the significant volumetric change according to the change of water content. Expansive soil is found in many places in the world. In wet season it absorbed large amounts of water and swell. In the dry season it shrink and become stiffer [1-2-3]. Expansive soil is considered one of the most important causes of the collapse of buildings and facilities [4-5-6-7-8].

Damage of buildings and infrastructure occurred when differential movements beyond the limits of what the structures or infrastructure can withstand. There are many factors affecting the stability of structures constructed on expansive soils. Environmental change can cause a change in soil moisture content and the ground water table level [9-10-11].

To determine the economical and safe design of buildings and facilities resting on expansive soil, three characteristics are required: swelling pressure, free swell, and swelling percent [12-13]. Several methods are available for treatment of the expansive soils. Replacement the expansive soil with non- swelling soil is the common way for treatment of the expansive soil. The factors required are the depth of the removal soil and the type of the replacement [14-15].

Alnmr A., Ray R., (2023) [16] studied the effect of replacement on the differential heave of the expansive soil due to climate conditions. They found that the replacement thickness should be not less than 1.0 m. Furthermore, the permeability of replacing soil should be lower than the permeability of the site soil to reduce the soil heave.

Loukidis D. et al., (2019) [17] presented a constitutive model to simulate the interaction between the expansive soil and raft foundation.

Soils and rocks in Egypt are characterized by a deficiency of moisture due to the high rate of evaporation and the dry climate. Numerous areas of Egypt consist of expansive soil, particularly the new cities.

In this paper, numerical analysis was carried out on the swelling soil obtained from Al- Azhar university branch, Sohage government in Upper Egypt. Also, a parametric study was carried out to examine the effect of some parameters like: the type of replacement, the thickness of replacement, and the ground water rise.

2. The Configuration of Numerical Model

The numerical study is performed using PLAXIS 3D ver. 24. Plaxis software was selected to perform the analysis due to its known reputation for solving complex geotechnical problems. The dimensions of the numerical model are chosen to be as illustrated in Figure (1) where, model width and length equals 60m while, the depth the model is 10m. These dimensions are considered large enough to minimize the boundary effects. The 10-node tetrahedral elements' mesh is utilized in the current study. The mesh size used is a default medium mesh size with automatic mesh refinement around the structural elements using the feature of enhanced mesh refinement in Plaxis software. The researched building is a typical 8.0 floors and its foundation are isolated footing system where, the external isolated footing (F1) has dimensions 2.0*2.0*1m, while interior footing (F2) has dimensions of 3.0*3.0*1 m as shown in Fig.1. All footings were connected together with a ground beam with a section of (0.3*0.8m). The flat slab floors of thickness 0.2m are modelled using plate elements. While columns are modelled using beam element.

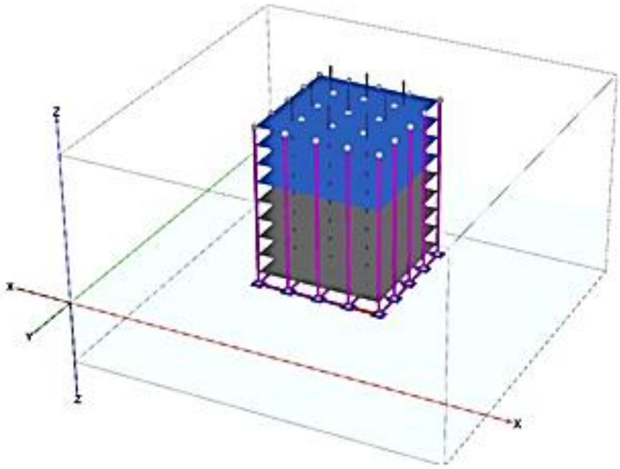

Fig. 1 Numerical model geometry

The soils are modelled using an advanced soil model called hardening soil model (HS). The HS model required 10 soil parameters input as follows: angle of shearing resistance (ϕ), the cohesion of soil c, dilatancy angle (Ψ), Primary oedometer load stiffness E_{oed}^{ref}, modulus of elasticity E_{50}^{ref}, unloading- reloading modulus E_{ur}^{ref} and power (m). Dilatancy angle (Ψ) was estimated using relation Ψ = ϕ - 30° as suggested in Plaxis manual [18]. Tables 1&2 present the input parameters used.

Table 1. Input parameters used in the analysis for modelling of soils

(After Abd el-samea et al. 2022) [19].

Parameter	Swelling Soil
Thickness (m)	**10**
Unsaturated Unit weightγ (kN/m^3)	**21.7**
Saturated Unit weight γ (kN/m^3)	**23**
Friction angle φ (Degree)	**30°**
Cohesion(C) kPa	**50**
Dialtency angle (ψ) (Degree)	**0°**
Poisson's ratioυ_{ur}	**0.2**
E_{50}^{ref} (Mpa)	**10.1**
E_{oed}^{ref} (Mpa)	**10.1**
E_{eur}^{ref} (Mpa)	**30.3**

Table 2. Input parameters used in the analysis for modeling of structural elements

Parameter	Columns	Floors	Footings	Ground Beam
Thickness (m)	0.5x0.5	0.2	1	0.3x0.8
Unit weight γ (kN/m^3)	25	25	25	25
Modulus of elasticity E (kPa)	$2.1x10^7$	$2.1x10^7$	$2.1x10^7$	$2.1x10^7$
Poisson's ratio υ	0.2	0.2	0.2	0.2

2.1 Verification of the numerical model

Numerical model verification was carried out to evaluate the accuracy of current study model with previous research [19] model. The geometry of verification model is shown in fig. 2.

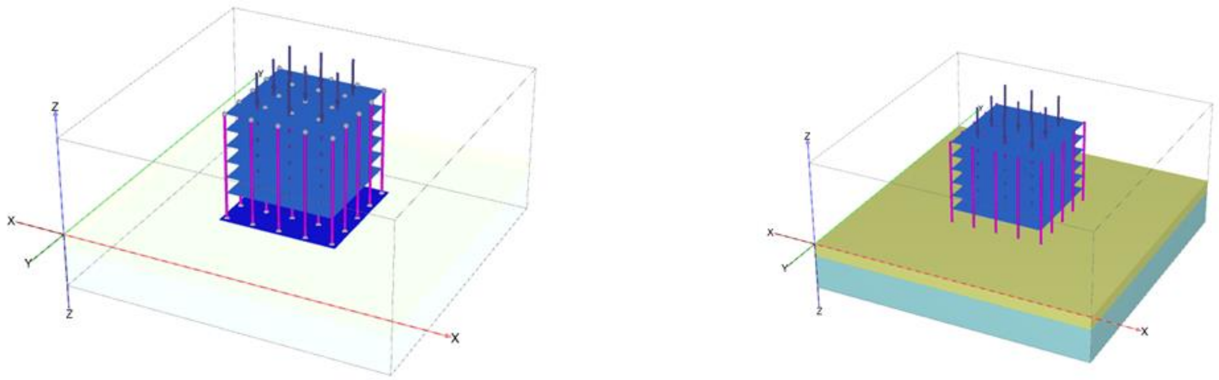

Fig. 2 Verification model geometry

Figure 3 shows average soil heave or expansion under foundation obtained by a previous researcher Abd el-samea et al. (2022) [19] versus the results obtained using the current model.

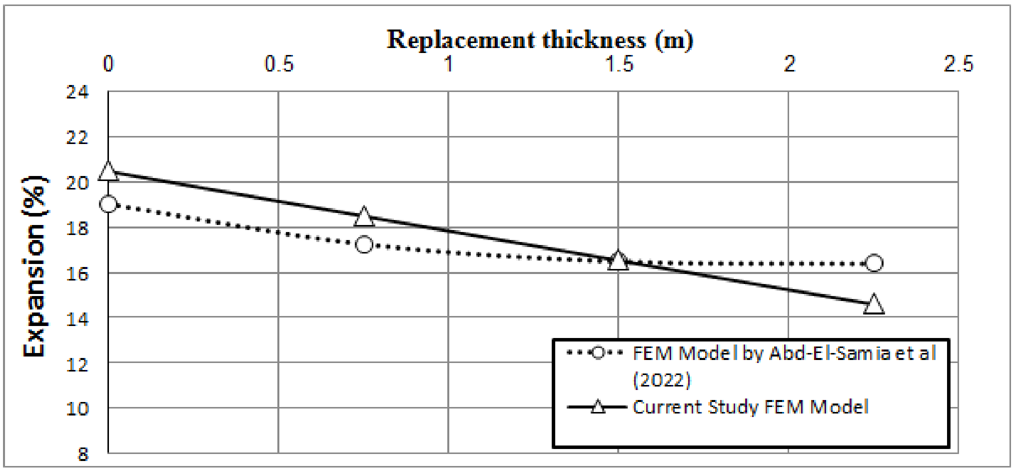

Fig. 3 Comparison between current model results and results by (Abd el-samea et al. 2022) [19]

Where: expansion % is the percentage of the heave corresponding to the total thickness of swelling soil layer.

From fig. 3 it was concluded that a good agreement between current model results and that obtained by a previous researcher Abd el-samea et al. (2022) [19].

2.2 Simulation of expansive soil

For numerical analysis calculations, three stages are chosen as follow:

- **Initial phase:** in this phase the generation of the initial stresses is performed using the K_o procedure.
- **Stage 1:** Construction of the superstructure and foundation is the first stage (no swelling stage), and applying building loads.
- **Stage 2:** applying the expansive clay soil's swelling capacity using volumetric strain.

The swelling of the expansive soil layer is modeled by applying positive volumetric strain of 26.4%. The value of volumetric strain is obtained from the average value of swelling under stress equal to 2.0 kg/cm^2 (average stress resulting from building loads) [19]. To simplify the analysis, the volumetric strain was uniformly applied across the full depth of the swelling soil layer [20].

Fig. 4 shows the numerical model configuration used in the analysis

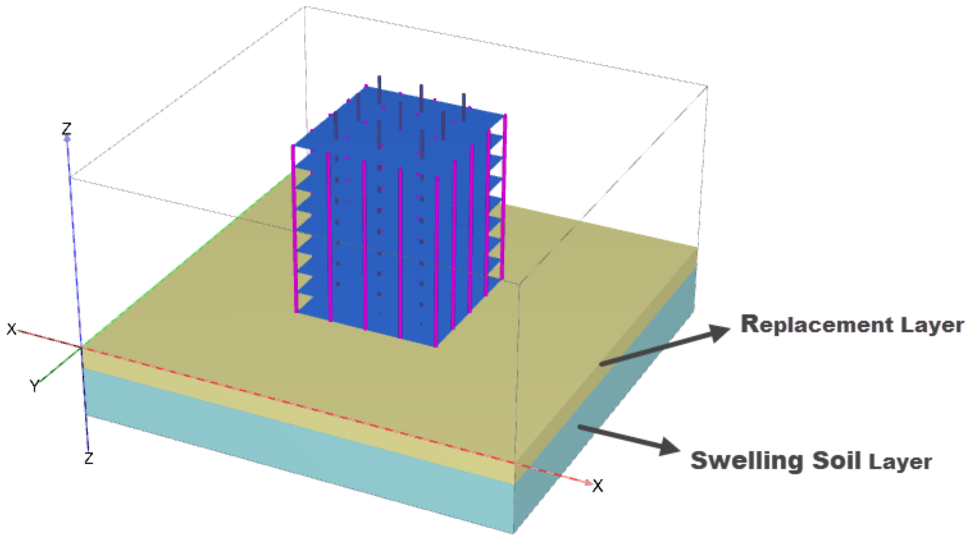

Fig. 4 Numerical model configuration

3. Effect of the Type of Replacement

In the present section, the numerical simulation was carried out for different types of replacement. The replacement type was varied as follow:

Sand, sand with gravel with ratio 1:1, and sand with gravel with ratio 1:2. Table 3 present the input parameters used.

Table3. Input parameters used in the analysis for modeling of soils

Parameter	Sand	Sand & Gravel (1:1)	Sand & Gravel (1:2)
Thickness (m)	1	1	1
Unsaturated Unit weight γ (kN/m^3)	18.6	20	21
Saturated Unit weight γ_{sat} (kN/m^3)	20	21	22
Friction angle φ(Degree)	35°	40°	41°
Cohesion(C) kPa	0	0	0
Dialtency angle (ψ) (Degree)	5°	10°	11°
Poisson's ratio υ_{ur}	0.2	0.2	0.2
E_{50}^{ref} (Mpa)	25	48	63
E_{oed}^{ref} (Mpa)	25	48	63
E_{eur}^{ref} (Mpa)	75	144	189

As shown in Figure 8, there is no remarkable change in expansion % with changing the replacement type. However, in the case of using sand as the replacement layer, the expansion % value was minimal.

Where: expansion % is the percentage of the heave corresponding to the total thickness of swelling soil layer

The maximum shear force increased by 8% when using a replacement layer consists of sand and gravel with ratio (1:1). Furthermore, when using a replacement layer consists of sand and gravel with ratio (1:2) the maximum shear force increased by 10 % as shown in Figure 6.

From Figure 7, it can be noticed that the maximum bending moment increased by 8.3% when using a replacement layer consists of sand and gravel with ratio (1:1) compared to using sand only as a replacement layer. Furthermore, when using a replacement layer consists of sand and gravel with ratio (1:2) the maximum bending moment increased by 11% compared to using sand only as a replacement layer. From the information mentioned above, it can be concluded that using sand only as a replacement layer gives lower values for bending moments and shear forces. This is due that the sand grains move to dissipate the swelling pressure.

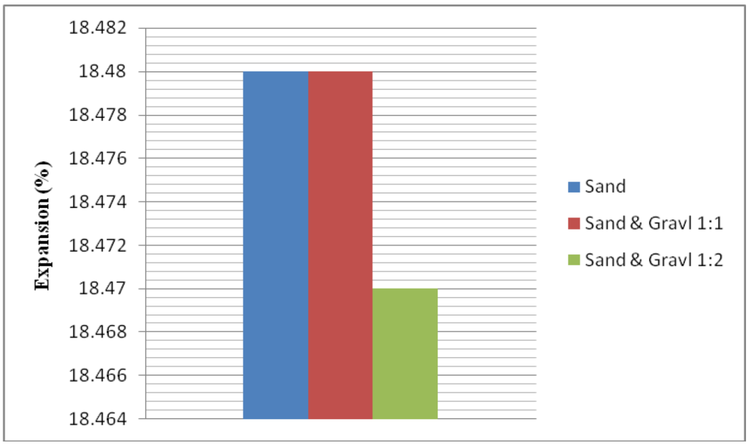

Fig. 5 The relation between the expansion % and the type of replacement

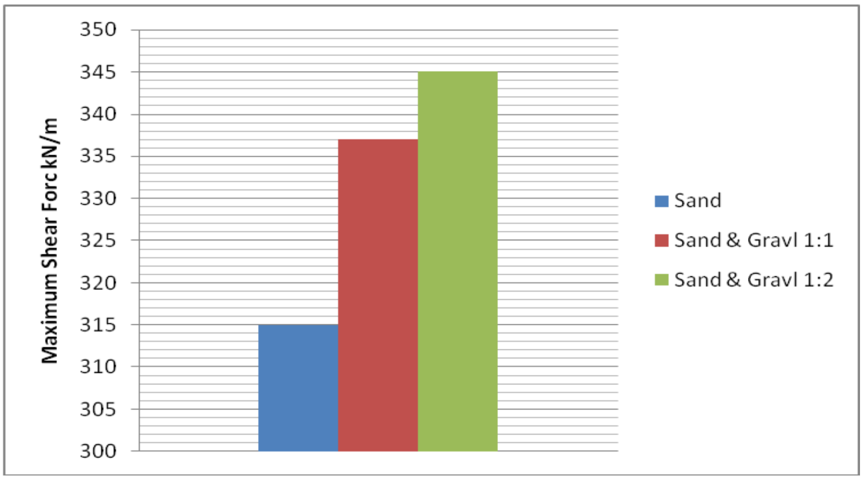

Fig. 6 The relation between the maximum shear force and the type of replacement

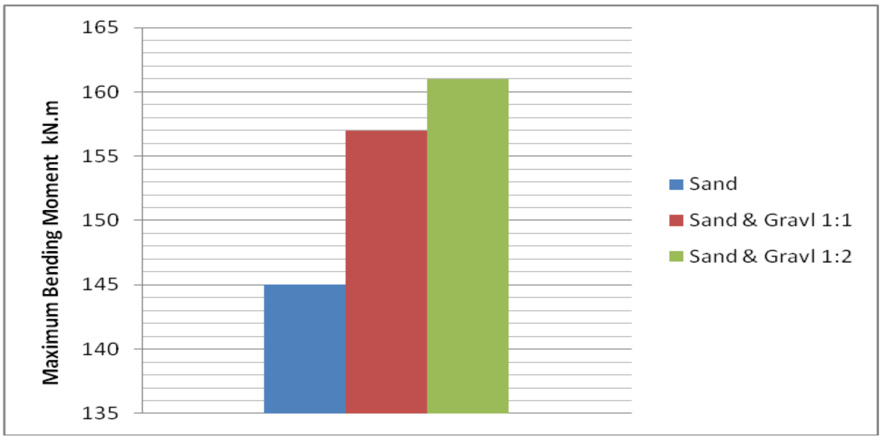

Fig. 7 The relation between the maximum bending moment and the type of replacement

4. Effect of the Replacement Thickness

In this section, the effect of the replacement thickness was simulated. The replacement thickness was varied from 0.5 m to 2m.

From the numerical results, it is clear that the thickness of replacement has a significant influence on the bending moment, shear force, and heave of soil.

The bending moment decreased by 22 % when the thickness of replacement increased from 0.5m to 1.0 m. When the thickness of replacement increased from 1.5m to 2.0 m, there was no significant change in the value of the bending moment as sown in Figure 8.

Moreover, the shear force decreased by 42 % when the thickness of replacement increased from 0.5m to 1.0 m, and by 5% when using 1.5m thickness of replacement. When the thickness of replacement increased from 1.5m to 2.0 m, there was no significant change in the value of the shear force as sown in Figure 9.

It can be distinguished that increasing the thickness of the replacement caused decrease in the shear forces and bending moments. This is because increasing the thickness of the replacement layer results in a decrease in the thickness of the swelling layer of the soil.

Furthermore, when the thickness of the replacement layer exceeds 1.5 m, this increase does not significantly affect the value of the bending moment and shear force. This is because when using replacement layer with thickness more than 1.5 m, the swelling pressure value becomes so small.

Also, the expansion % decreased as the thickness of replacement layer increased as shown in Figure10.

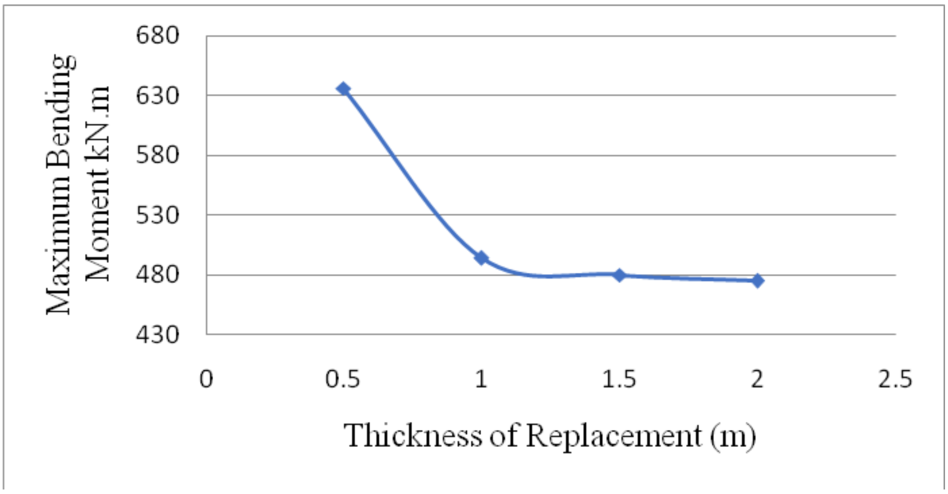

Fig. 8 The relation between the maximum bending moment and the thickness of replacement

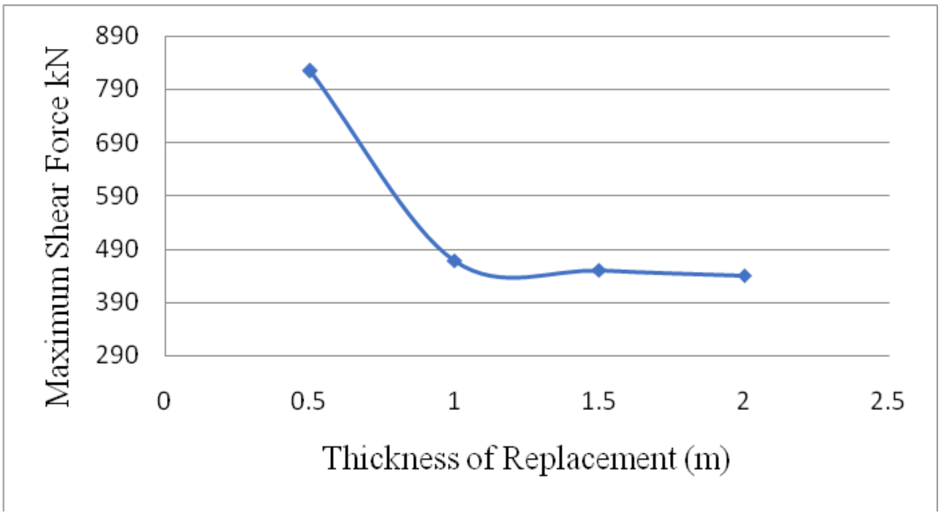

Fig. 9 The relation between the maximum shear force and the thickness of replacement

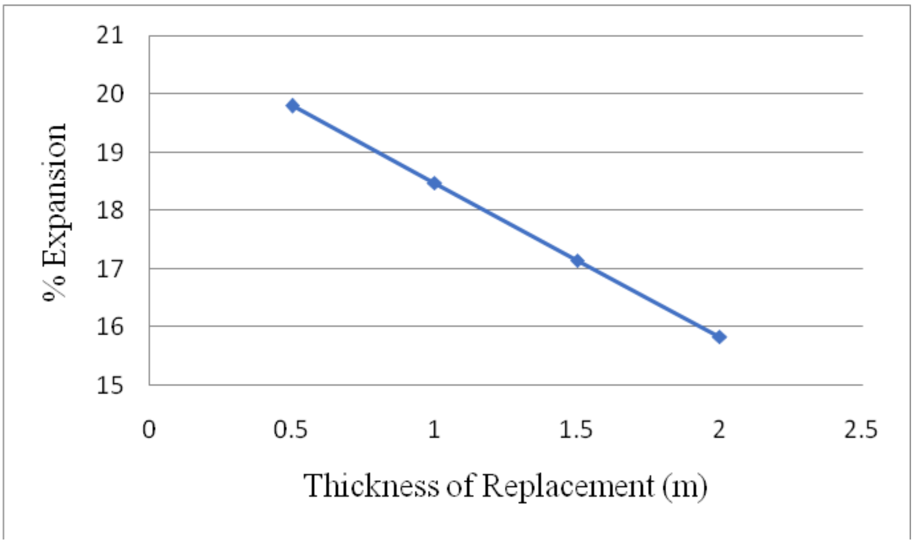

Fig. 10 The relation between the expansion % and the thickness of replacement

5. Effect of Ground Water Table Level

Ground water rise change the stress in soil under foundation. Also, that causes decrease of effective stress and increase the pore water pressure. In case of expansive soil, an additional problem may be occurred.

To study the effect of groundwater rise, a finite element analysis was carried out to determine the influence of the ratio D/B on the behaviour of the expansive soil. Where (B) is the width of foundation ad (D) is the depth of groundwater from the ground surface.

As shown in Figures 11&12, in the case of no replacement layer under the foundations, the maximum bending moment and shear force occurred at D/B=0. Moreover, the maximum bending moment and shear force decreased as the ratio D/B increased. This is because the heave decreased as the groundwater level decreased as shown in Figure 13. Also, when the ratio D/B was greater than three, the effect of groundwater disappeared.

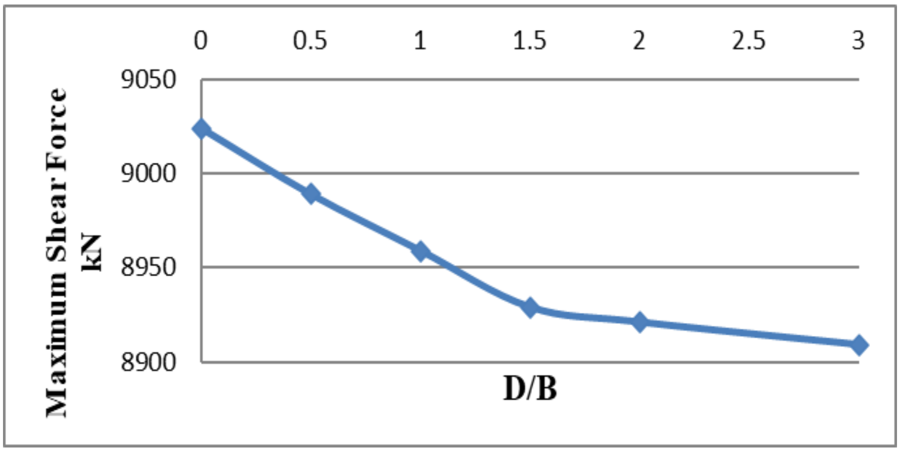

Fig. 11 The relation between the maximum shear force and the ratio D/B (without replacement)

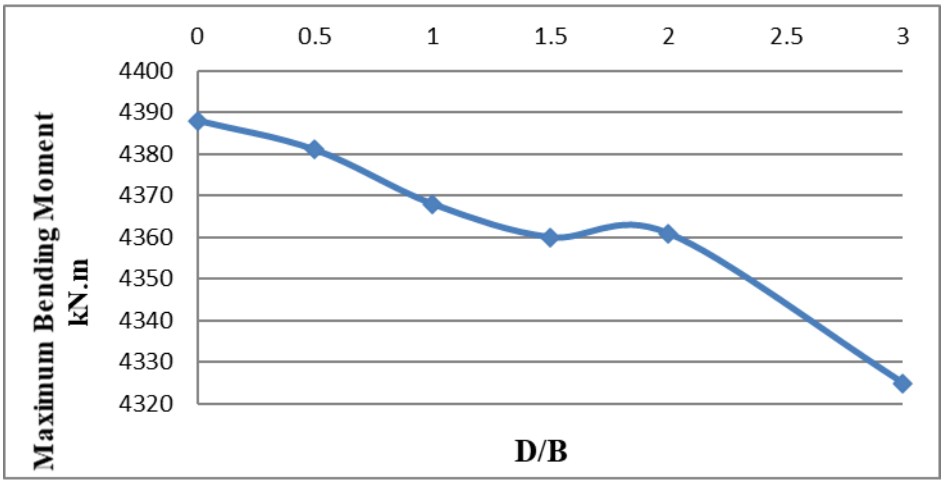

Fig. 12 The relation between the maximum bending moment and the ratio D/B (without replacement)

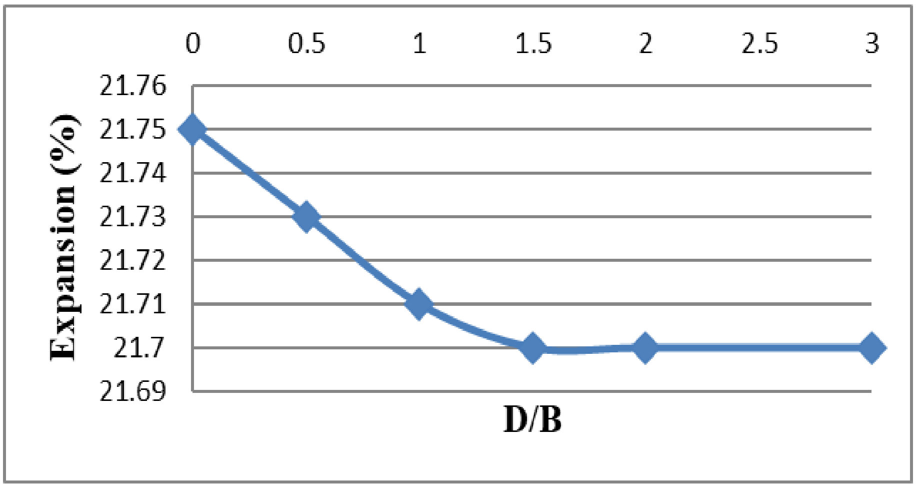

Fig. 13 The relation between expansion % and the ratio D/B (without replacement)

According to the finite element analysis, there is no remarkable change occurred due to rise of groundwater level in the case of using sand with 1.0 m thickness as a replacement. Furthermore, a limited increasing in maximum bending moment less than 1% occurred when D/B=1 as shown in Figure 14.

The same thing occurred to shear force but the maximum shear force occurred at D/B = 0.5 as shown in Figure 15. The effect of the change in the groundwater level was very limited and almost non-existent. This is because the heave was constant with all cases of D/B as shown in Figure 16.

According to the information mentioned above, using the sand as a replacement layer under foundations constructed on expansive soil dissipated the effect of the change in groundwater level.

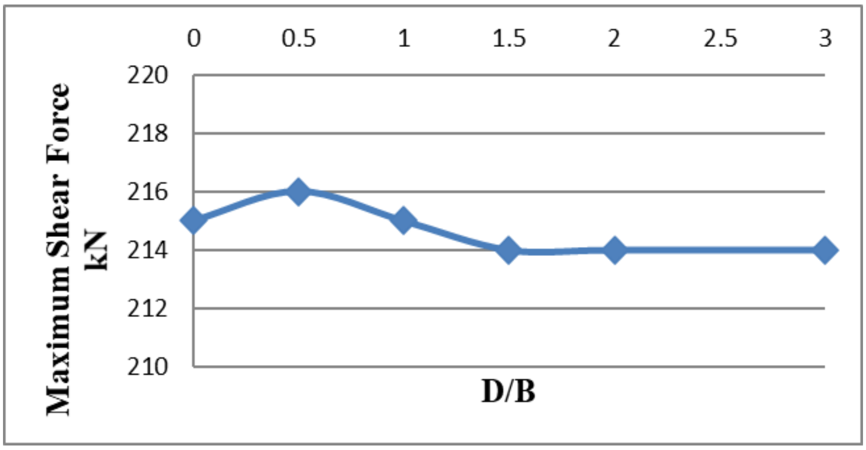

Fig. 14 The relation between the maximum shear force and the ratio D/B (with replacement)

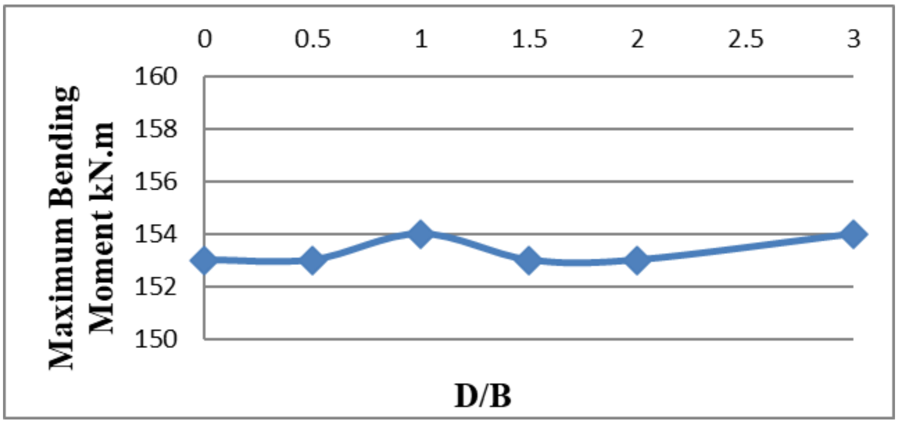

Fig. 15 The relation between the maximum bending moment and the ratio D/B (with replacement)

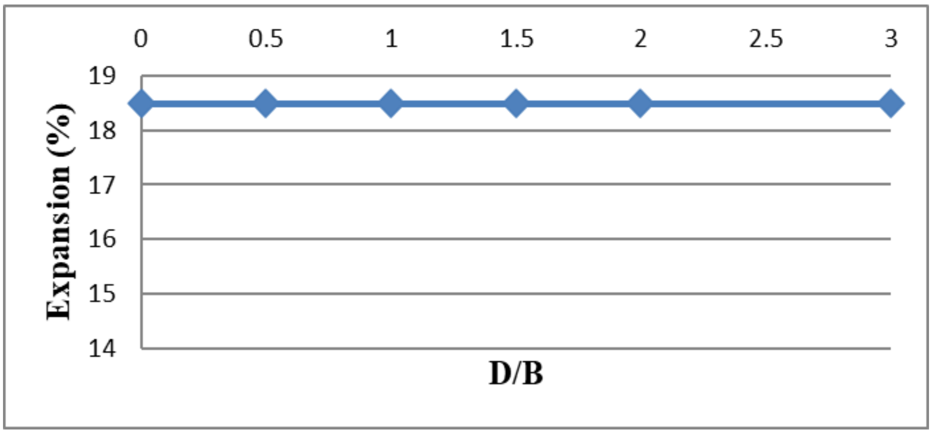

Fig. 16 The relation between % expansion and the ratio D/B (without replacement)

6. CONCLUSIONS

Based on the finite element analysis, the following conclusions can be drawn:

1-Using a replacement layer of sand only gives lower bending moment and shear force values than using replacement layers consisting of sand and gravel.

2-The maximum bending moment and shear force decreased as the ratio D/B increased.

3- The effect of groundwater level disappeared when the ratio D/B was greater than 3.

4-Using sand as a replacement layer under foundations constructed on expansive soil dissipated the effect of the change in groundwater level.

5-Increasing the thickness of the replacement layer cause decrease in the shear forces and bending moments.

CONFLICT OF INTEREST

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

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