J. Umm Al-Qura Univ. Eng.Archit.
https://doi.org/10.1007/s43995-024-00073-1

ORIGINAL ARTICLE

# Assessing the effects of different foundation base shapes on settlement and heaving in expansive clay: numerical analysis

**Walaa-Eldin Elsherif Mohamed**[1]

Received: 2 May 2024 / Accepted: 23 June 2024


**Abstract**
This paper investigates the behavior of shallow foundations with different base shapes on expansive soils under various Stresses conditions and different slopes of the base. Expansive soils are soils that undergo significant volume changes due to variations in moisture content, which can cause severe damage to structures built on them. The shape of the foundation base can influence the magnitude and distribution of the soil pressures, as well as the deformation and cracking of the foundation. The paper presents a numerical analysis using a finite element method with Plaxis 3D. The paper also proposes some recommendations for the optimal design of foundation base shapes on expansive soils. The numerical results show that the foundation base shape has a significant effect on the stress and displacement distributions in the soil and the foundation and that some shapes perform better than others in terms of reducing the soil pressures. The paper provides some useful insights for the design and construction of shallow foundations on expansive soils.

**Keywords** Soft clay · Experimental work · Elliptical footing · Bottom of foundations · Numerical analysis · Settlement · Heave · Wedge foundation · Triangle foundation

## 1 Introduction

Expansive soils are known for their ability to swell when exposed to water and shrink when dried, leading to potential damage to structures built upon them [1]. The design and performance of foundations on such reactive soils are critically influenced by the interplay between soil properties, environmental conditions, and the geometry of the foundation itself. Among the various factors, the shape of the foundation base plays a pivotal role in dictating the stress distribution and consequent soil-structure interaction [2]. The shape of the foundation base influences the distribution of stresses and the interaction with the underlying soil, thereby affecting the potential for differential settlement and structural damage [3].

Through a comprehensive review of existing literature and case studies, we will analyze how different foundation shapes affect soil-structure interaction, with a particular focus on mitigating damage and enhancing the durability of structures built on expansive soils. The methodologies adopted in various studies, such as the soil-structure interaction analysis [4], the design considerations for deep foundations as discussed [2], and, the 3D analysis conducted [5] highlight the structural implications of irregular-geometry foundations under expansive soil effects. The foundation design in expansive soils will be scrutinized to comprehend its nuances.

Plaxis 3d Different base foundation shapes, such as Triangle, Wedge, double wedge, and circular base shapes, have been studied with change in base slope to understand their effectiveness in mitigating the challenges posed by expansive soils. Additionally, the settlement of shallow foundations on expansive clay before it heaves has been considered for their effects on the overall behavior of the foundation.

The expected outcome of this research is to provide a better understanding of the mechanisms and factors that affect the foundation performance on expansive clay and to propose some practical recommendations and guidelines for selecting and designing the optimal foundation shape for different scenarios. The ultimate goal is to contribute to the development of more effective design practices that enhance the resilience of structures built on expansive soils.

✉ Walaa-Eldin Elsherif Mohamed
Wala2_r@mhiet.edu.eg

[1] El Minya Higher Institute of Engineering and Technology, El Minya, Egypt

Published online: 02 July 2024

**Table 1** The value adopted expansive soil layer in Plaxis 3D

| Properties | Symbol | Values | Units |
|---|---|---|---|
| Young's modulus | $E_{50}^{ref}$ | 3500 | $kN/m^2$ |
| | $E_{ur}^{ref}$ | 10.5 E3 | $kN/m^2$ |
| Density | $\rho_{unsat}$ | 17 | $kN/m^3$ |
| | $\rho_{sat}$ | 19 | $kN/m^3$ |
| Poisson's ratio | υ | 0.2 | |
| Angle of friction | Ø | 10 | Degree |
| Cohesion | C | 40 | KPa |

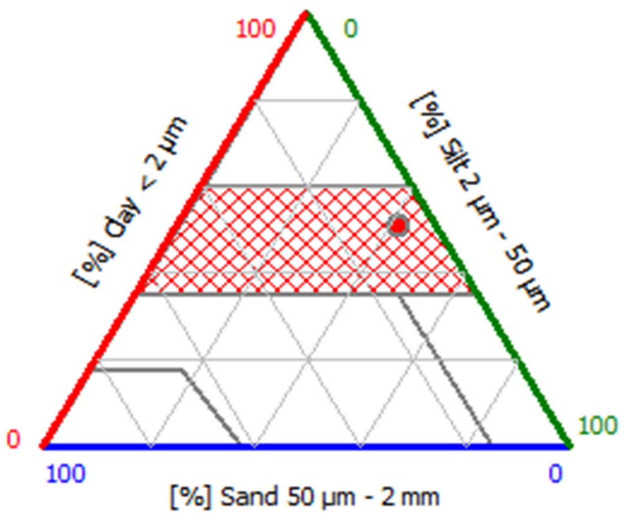


**Fig. 1** Textural classification of used soil (extracted from plaxis after adding soil particle sizes obtained from lab tests)

## 2 Numerical model and parametric study

### 2.1 Components of soil and foundation model

A 3-D numerical model was developed using Plaxis 3D V23 [6] to simulate the behavior of a footing and the underlying expansive clay. The footing dimensions were 3 m × 3 m × 1 m and was placed on the top of an expansive clay layer with dimensions of 9 m × 9 m × 6 m. The concrete material of the footing was assumed to be isotropic, linear elastic, and non-porous, while the expansive clay was modeled as a hardening soil with a volumetric strain of 6%

### 2.2 Expansive soil

An expansive clay dimension of 9 × 9 × 6 m thickness and its properties (that was obtained from laboratory tests on expansive soil sample was as follows) (Table 1 and Fig. 1).

The swelling deformation action is simulated by applying a positive volumetric strain to the active zone. Numerous researchers utilized this approach effectively to simulate the swelling of expansive soils, and it has proven to be effective [7–10].

### 2.3 Foundation

This study used five foundation base shapes: flat, triangular, wedge, oval, and double-direction wedge. Each shape has nine different slopes to test its settlement when the soil is dry and its heave when the soil expands.

### 2.4 Testing procedure

The analysis consisted of three steps:

The first step was to remove (3 × 3 × 1 m) of the soil and place the foundation base in the middle of the removed soil. In this step, the soil was dry and settled under its own weight and foundation weight.

The second step was to apply a vertical stress of 11.1, 22.2, or 33.3 $t/m^2$ on the footing while the soil remained dry and the settlement of the Foundation Base was measured.

The third step was to add moisture to the expansive soil induce a volumetric strain of 6% in the soil and measure the heave of Foundation Base.

## 3 Results and discussion

Several numerical simulations were carried out with different stresses, different base shapes, and different base side slopes to evaluate the settlement before heaving and heaving values after adding volumetric strain to the expansive clay of the footing constructed on expansive soils. Using the assumptions stated above, the relevant results of deformations at various points are calculated. The numerical results of these scenarios were obtained and explained in this section.

### 3.1 Settlement

In this stage, the footing was placed on a 6 m thickness of expansive soil before adding the moisture and loaded with weights of 100, 200, and 300 tons for each base shape at different base side slopes that equals to stresses of 11.1, 22.2, 33.3 $t/m^2$ respectively, Settlements were measured immediately after loading at the end of each loading cycle. It is important to note that the total net pressure considered the weight of the footing model along with the added load.

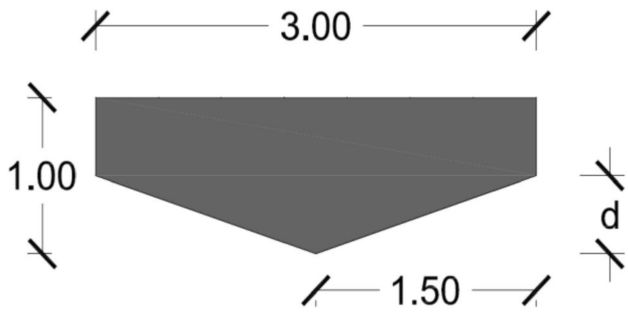


**Fig. 2** Explaining the shape and inclination of the triangular base shape

**Table 2** Slope values and dimensions of the triangular base shape

| Triangular base shape side slope (d/1.5) × 100 | d (cm) |
|---|---|
| Flat | 0 |
| 10% base side slopes | 15 |
| 15% base side slopes | 22.5 |
| 20% base side slopes | 30 |
| 25% base side slopes | 37.5 |
| 30% base side slopes | 45 |
| 35% base side slopes | 52.5 |
| 40% base side slopes | 60 |
| 45% base side slopes | 67.5 |
| 50% base side slopes | 75 |

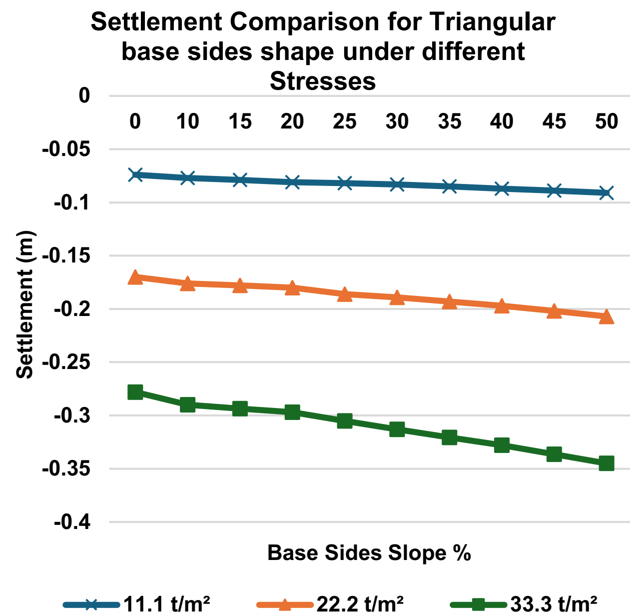


**Fig. 3** Relationship between triangular base sides slope and settlement curve for applied stresses of 11.1, 22.2, 33.3 t/m$^2$

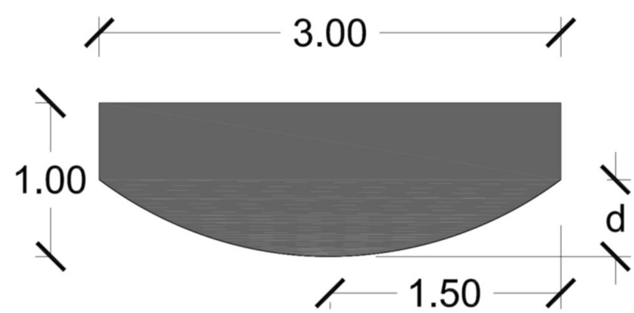


**Fig. 4** Explaining the shape and inclination of the oval base shape

### 3.1.1 Results of the triangular base shape

This group focuses on the Triangular bottom shape (Fig. 2) footing with varying side slopes (0% (Flat), 10%, 15%, 20%, 25%, 30%, 35%, 40%, 45% and 50%). The footing was placed on expansive soil before adding moisture and loaded with weights equal to 100, 200, and 300 tons that gives stresses of 11.1, 22.2, 33.3 t/m$^2$ (Table 2).

The test results for the Triangular Base Foundation Shape in Fig. 3. It can be noticed that the settlements increase with higher applied stress and steeper base side slopes. However, it was observed that when the applied stress is 33.3 t/m$^2$, the rate of settlements increases at a higher rate compared to lower stress levels.

### 3.1.2 Results of the oval base shape

This group focuses on the oval bottom shape (Fig. 4) footing with varying depth of footing sides till the start of bending (0% (Flat), 10%, 15%, 20%, 25%, 30%, 35%, 40%, 45%, and 50%) (Table 3).

The test results for the Oval Base Foundation Shape shown in Fig. 5 indicated that the settlements increase with the increase of higher applied stress but don't make a great

**Table 3** Slope values and dimensions of the oval base shape

| Oval base shape side slope (d/1.5) × 100 | d (cm) |
|---|---|
| Flat | 0 |
| 10% base side slopes | 15 |
| 15% base side slopes | 22.5 |
| 20% base side slopes | 30 |
| 25% base side slopes | 37.5 |
| 30% base side slopes | 45 |
| 35% base side slopes | 52.5 |
| 40% base side slopes | 60 |
| 45% base side slopes | 67.5 |
| 50% base side slopes | 75 |

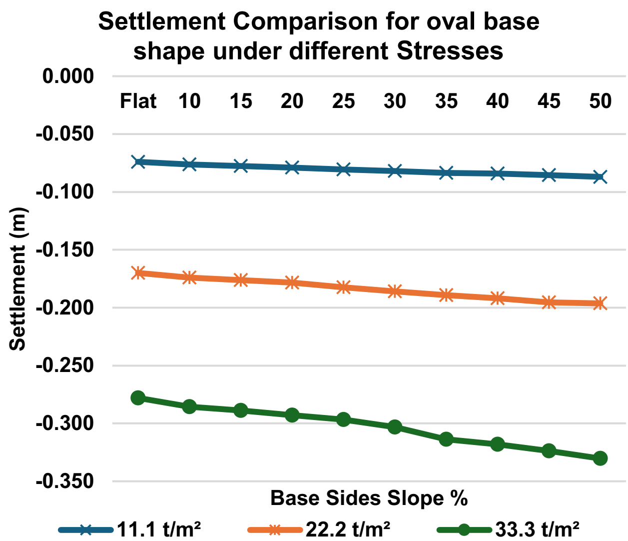


**Fig. 5** Relationship between oval base sides slope and settlement curve for applied stresses of 11.1, 22.2, 33.3 t/m$^2$

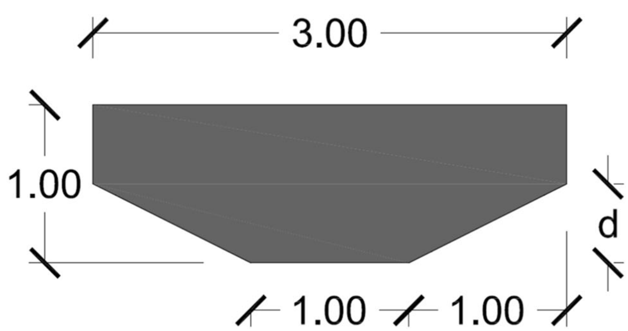


**Fig. 6** Explaining the shape and inclination of the wedge base shape

**Table 4** Slope values and dimensions of wedge base shape

| Wedge shape side slope (d/1.0) × 100 | d (cm) |
|---|---|
| Flat | 0 |
| 10% base side slopes | 10 |
| 15% base side slopes | 15 |
| 20% base side slopes | 20 |
| 25% base side slopes | 25 |
| 30% base side slopes | 30 |
| 35% base side slopes | 35 |
| 40% base side slopes | 40 |
| 45% base side slopes | 45 |
| 50% base side slopes | 50 |

difference with changing the oval length. However, it was observed that when the applied stress is 33.3 t/m$^2$, the rate of settlements increased at a higher rate compared to the lower stress.

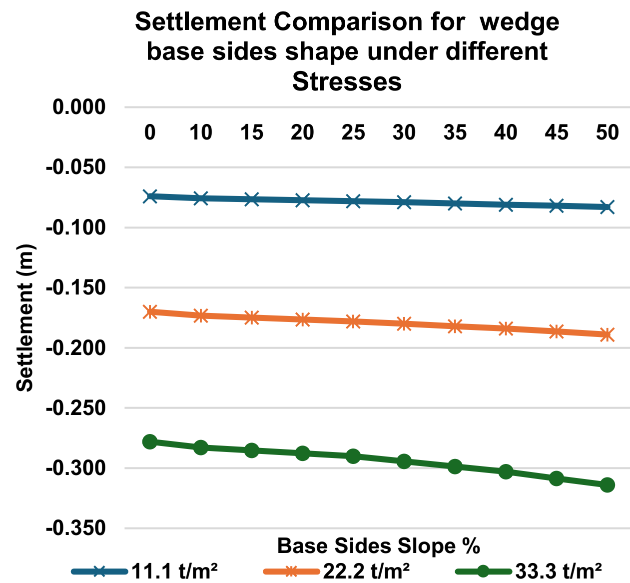


**Fig. 7** Relationship between wedge base sides slope and settlement curve for applied stresses of 11.1, 22.2, 33.3 t/m$^2$

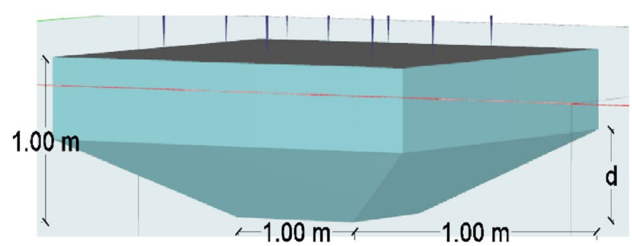


**Fig. 8** Explaining the shape and inclination of the double wedge base shape

### 3.1.3 Results of the wedge base shape

This group focuses on the bottom wedge shape of footing (Fig. 6) with varying side slopes (0% (Flat), 10%, 15%, 20%, 25%, 30%, 35%, 40%, 45% and 50%) (Table 4).

The test results for the wedge Base Foundation Shape were plotted in Fig. 7, it's indicated that the settlements increase with the increase of higher applied stress and steeper base side slopes. However, it was observed that when the applied stress is 33.33 t/m$^2$, the rate of settlements increases at a higher rate compared to lower stress levels.

### 3.1.4 Results of the double wedge base shape

This group focuses on the Double Wedge of bottom shape footing with varying side slopes (0% (Flat), 10%, 15%, 20%, 25%, 30%, 35%, 40%, 45%, and 50%) as shown in Fig. 8 (Table 5).

**Table 5** Slope values and dimensions of double wedge base shape

| Double wedge shape side slope (d/1.0)×100 | d (cm) |
|---|---|
| Flat | 0 |
| 10% base side slopes | 10 |
| 15% base side slopes | 15 |
| 20% base side slopes | 20 |
| 25% base side slopes | 25 |
| 30% base side slopes | 30 |
| 35% base side slopes | 35 |
| 40% base side slopes | 40 |
| 45% base side slopes | 45 |
| 50% base side slopes | 50 |

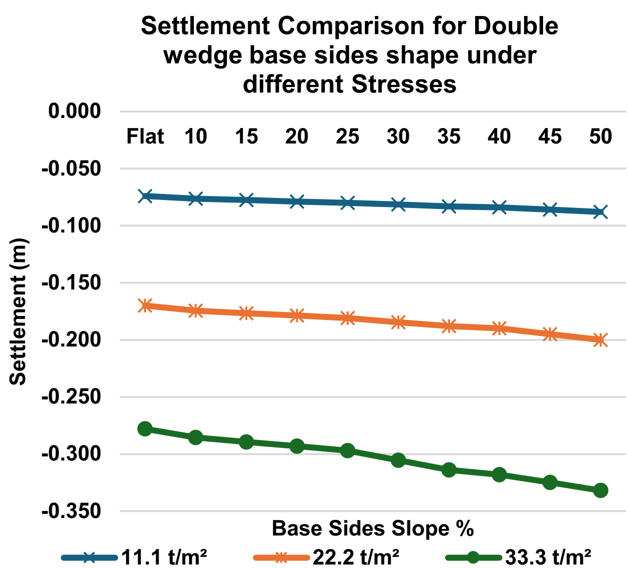


**Fig. 9** Relationship between double wedge base sides slope and settlement curve for applied stresses of 11.1, 22.2, 33.3 t/m$^2$

The test results for the double wedge Base Foundation Shape in Fig. 9 indicated that the settlements increased with higher applied stress and steeper base side slopes. However, it was observed that when the applied stress is 33.3 t/m$^2$, the rate of settlements increases at a higher rate compared to lower stress levels.

## 3.2 Heaving

In this stage, the footing was placed on a 6 m thickness of expansive soil, adding a volumetric Strain of 6% and without lifting the existing stress from the previous stage, whether it was 11.1, 22.2 and 33.3 t/m$^2$ for each base shape with different base side slopes. Heave was measured with the existence

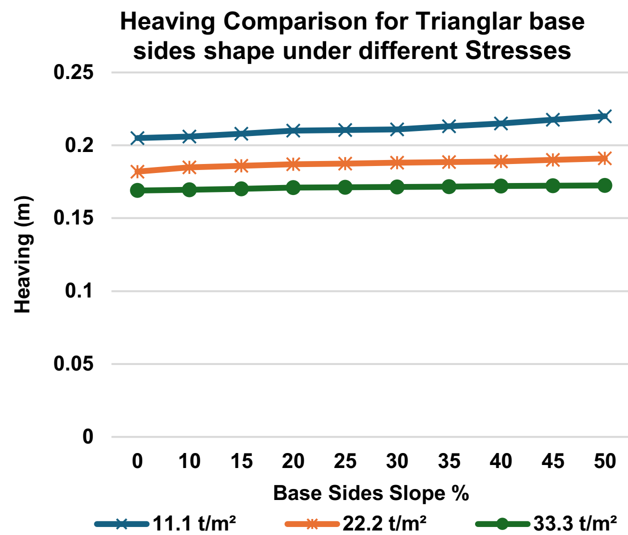


**Fig. 11** Relationship between oval base sides slope and heaving curve for applied stresses of 11.1, 22.2, 33.3 t/m$^2$

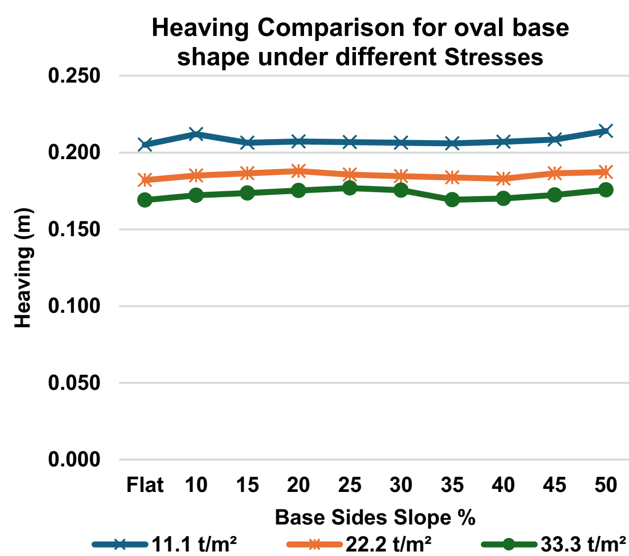


**Fig. 10** Relationship between triangular base sides slope and heaving curve for applied stresses of 11.1, 22.2, 33.3 t/m$^2$

of load on the foundation at the end of each heaving, and it's measured for this stage only.

### 3.2.1 Results of the triangular base shape

For the Triangular Base Foundation Shape from Fig. 10 can be noticed that the heaving increases with the decrease of applied stress. However, altering the side slope of the foundation base results in a slightly higher rate of foundation heave for 22.2 and 33.3 t/m$^2$. It was observed that when the applied stress is 11.1 t/m$^2$, the rate of heaving increases at a higher rate compared to lower stress levels.

### 3.2.2 Results of the oval base shape

The test results for the Oval Base Foundation Shape shown in Fig. 11 indicated that the heaving increases with the decrease of applied stress. However, altering the side slope of the foundation base doesn't influence the rate of foundation heave much.

### 3.2.3 Results of the wedge base shape

The test results for the Wedge Base Foundation Shape shown in Fig. 12 indicated that the heaving increases with the decrease of applied stress. However, altering the side slope of the foundation base doesn't have a great influence on the rate of foundation heave.

### 3.2.4 Results of the double wedge base shape

The test results for the double wedge base Foundation Shape shown in Fig. 13 indicated that the heaving increases with the increase of lower applied stress. However, altering the side slope of the foundation base results in a higher rate of foundation heave slight increase.

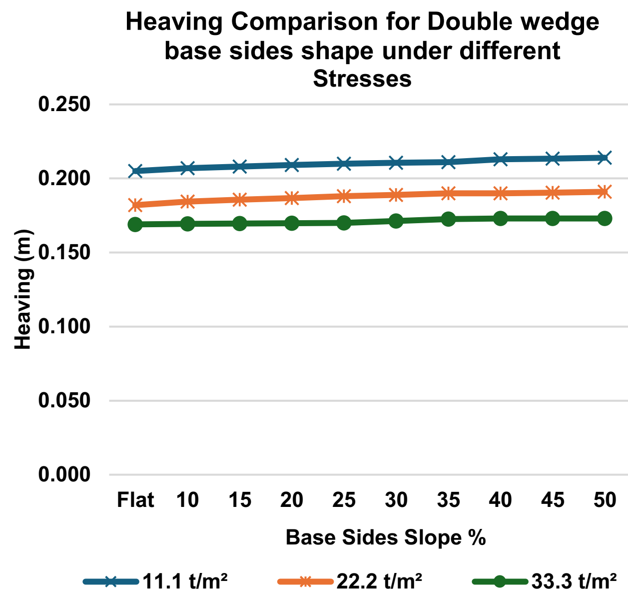


**Fig. 13** Relationship between double wedge base side's slope and heaving curve for applied stresses of 11.1, 22.2, 33.3 t/m$^2$

## 3.3 Total settlement

Here, the total settlements of footing were measured after the settlement of footing and heaving of soil for all footing base shapes.

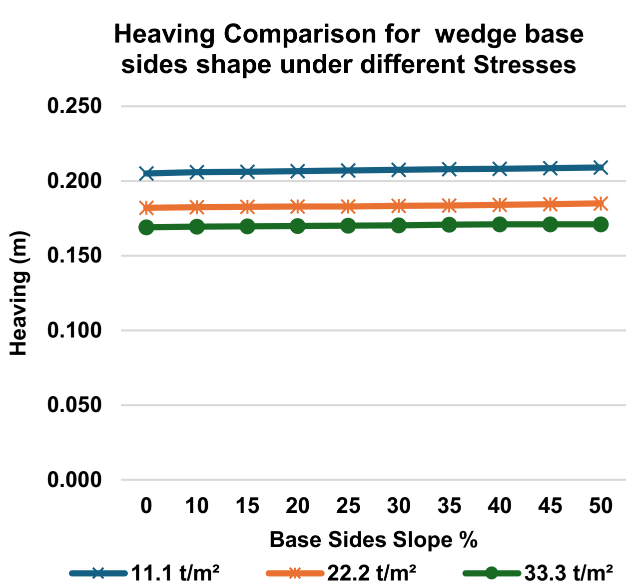


**Fig. 12** Relationship between wedge base sides slope and heaving curve for applied stresses of 11.1, 22.2, 33.3 t/m$^2$

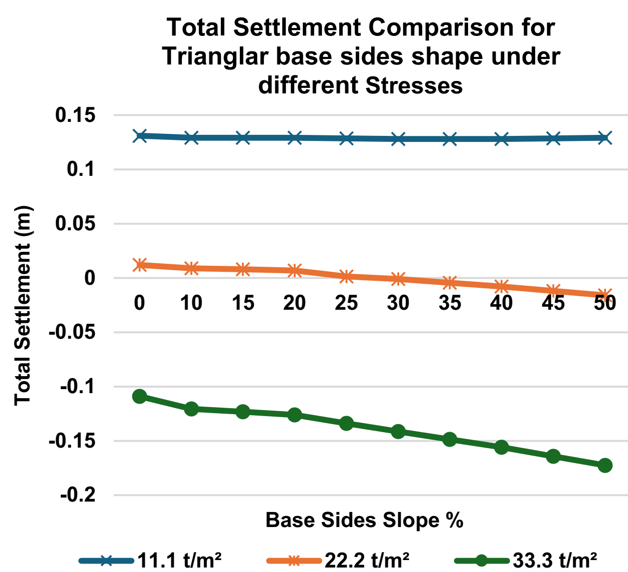


**Fig. 14** Relationship between triangular base sides slope and total settlement curve for applied stresses of 11.1, 22.2, 33.3 t/m$^2$

### 3.3.1 Results of the triangular base shape

The test results for the triangular base shape shown in Fig. 14 indicated that for stress 11.1 t/m$^2$, heaving was more powerful than settlement that the overall settlement was positive.

For 22.2 t/m$^2$ with 0–20% base side slopes, heave was larger than settlement and with the increase of foundation base slope gets to its origin so no positive or negative settlement, then from 40 to 50% a slight settlement occur.

For much larger stress 33.3 t/m$^2$ settlement was larger than heaving, so the overall settlement was to go down and with increasing the base side slope ratio it gets more settlement.

### 3.3.2 Results of the oval base shape

The test results of the oval base shape shown in Fig. 15 indicated that for 11.1 t/m$^2$ heaving was more powerful than settlement and the overall settlement was positive.

For 22.2 t/m$^2$ with 0–20% base side slopes heave was larger, then with the increase of the base side slopes from 25 to 30% heaving made the foundation get to its origin so no positive or negative settlement, then about 35–50% a slight settlement.

For much larger stress 33.3 t/m$^2$ settlement was larger than heaving, so the overall settlement was to go down and with increasing base side slope ratio it gets more settlement.

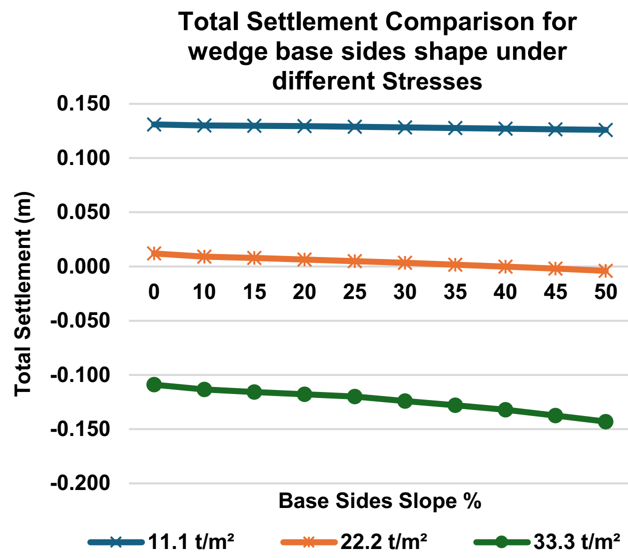


**Fig. 16** Relationship between wedge base sides slope and total settlement curve for applied stresses of 11.1, 22.2, 33.3 t/m$^2$

### 3.3.3 Results of the wedge base shape

The test results of the wedge base shape shown in Fig. 16 indicated that for 11.1 t/m$^2$ heaving was more powerful than settlement and the overall settlement was positive.

For 11.1 t/m$^2$ with 0–20% base side slopes heave was larger than with the increase of the base side slopes from 25 to 50% heaving made the foundation get to its origin so no positive or negative settlement.

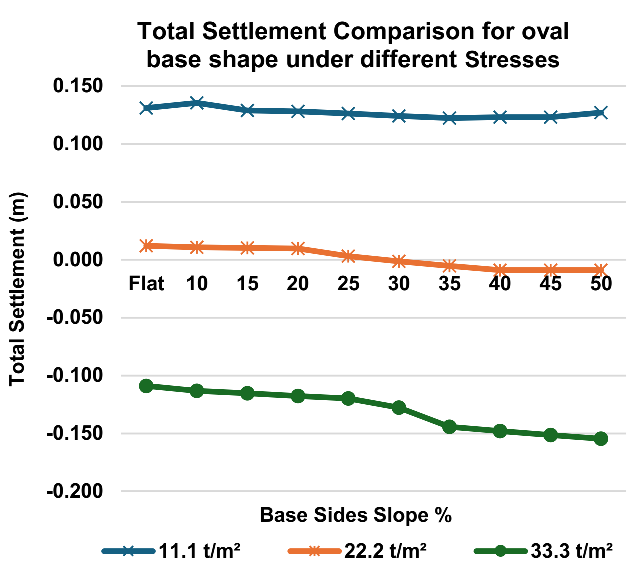


**Fig. 15** Relationship between oval base sides slope and total settlement curve for applied stresses of 11.1, 22.2, 33.3 t/m$^2$

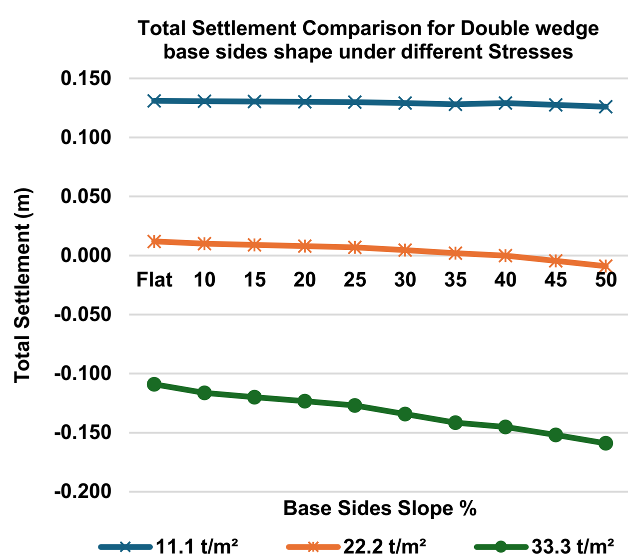


**Fig. 17** Relationship between double wedge base sides slope and total settlement curve for applied stresses of 11.1, 22.2, 33.3 t/m$^2$

For much larger stress 33.3 t/m$^2$ settlement was larger than heaving so the overall settlement was to go down and with increasing base side slope ratio it got more settlement.

#### 3.3.4 Results of the double wedge base shape

The test results of the double wedge base shape shown in Fig. 17 indicated that heaving was more powerful than settlement for 11.1 t/m$^2$, and the overall settlement was positive.

For 22.2 t/m$^2$ with 0–25% base side slopes heave was larger than with the increase of the base side slopes from 30 to 45% heaving made the foundation get to its origin so no positive or negative settlement, then from 50% a slight settlement.

For much larger stress 33.3 t/m$^2$ settlement was larger than heaving so the overall settlement was to go down and with increasing base side slope ratio it got more settlement.

### 3.4 Effect of different base side slope on the behavior for different shapes

#### 3.4.1 Settlement at certain stress

**3.4.1.1 Under stress of 11.1 t/m$^2$** Figure 18 shows that the triangular foundation base shape settles most under the stress equals 11.1 t/m$^2$ then the double wedge base shape then the oval and the wedge shape has the least settlement values.

Also, double wedges and oval have so much similar settlement values.

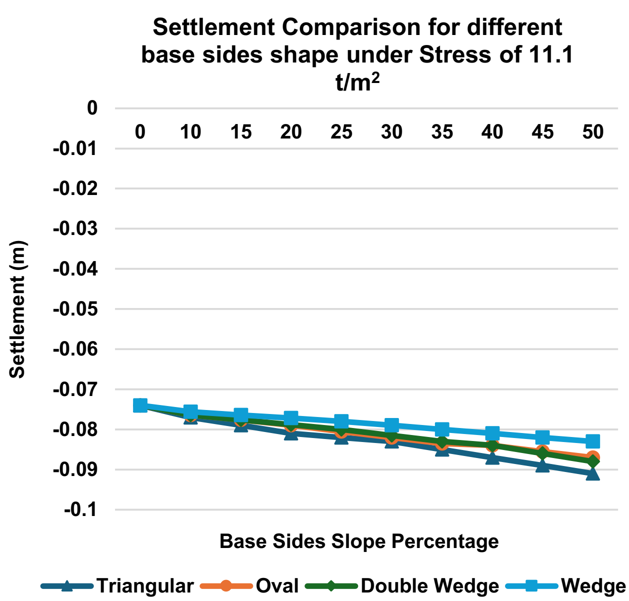


**Fig. 18** Relationship between base side slopes for different shapes and settlement curve for applied stress of 11.1 t/m$^2$

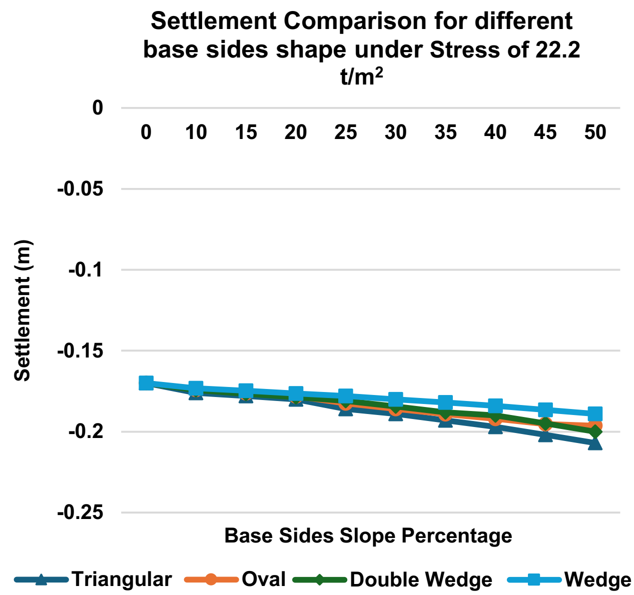


**Fig. 19** Relationship between base side slopes for different shapes and settlement curve for applied stress of 22.2 t/m$^2$

**3.4.1.2 Under stress of 22.2 t/m$^2$** Figure 19 shows that the triangular foundation base shape settles most under the stress equals 22.2 t/m$^2$ then the double wedge base shape then the oval and the wedge shape have the least settlement values.

Also, double wedges and oval have so much similar settlement values.

**3.4.1.3 Under stress of 33.3 t/m$^2$** Figure 20 shows that the triangular foundation base shape settles most under the

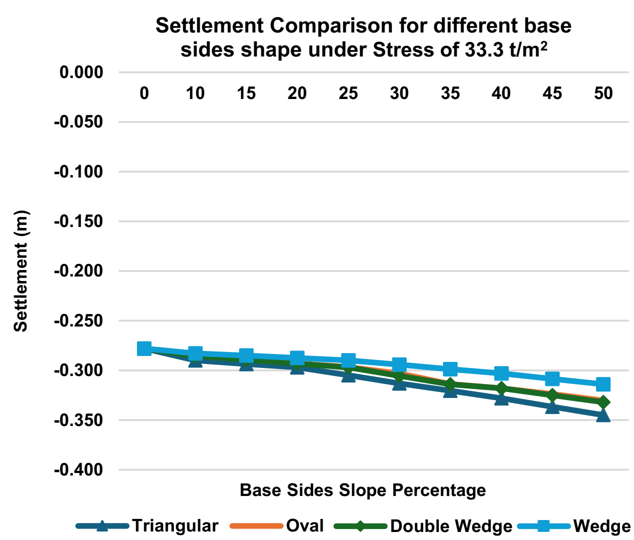


**Fig. 20** Relationship between base side slopes for different shapes and settlement curve for applied stress of 33.3 t/m$^2$

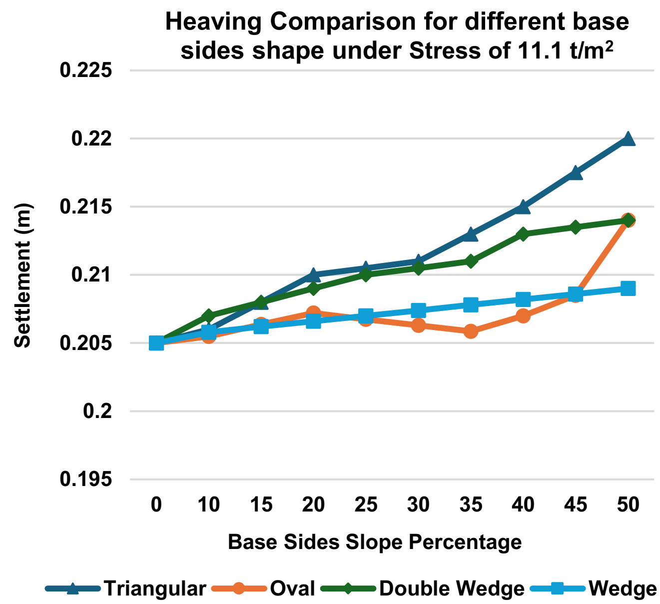


**Fig. 21** Relationship between base side slopes for different shapes and heaving curve with an applied stress of 11.1 t/m$^2$

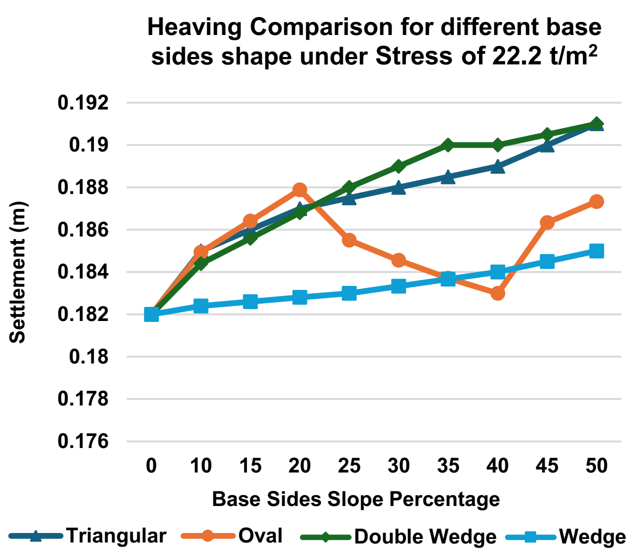


**Fig. 22** Relationship between base side slopes for different shapes and heaving curve with an applied stress of 22.2 t/m$^2$

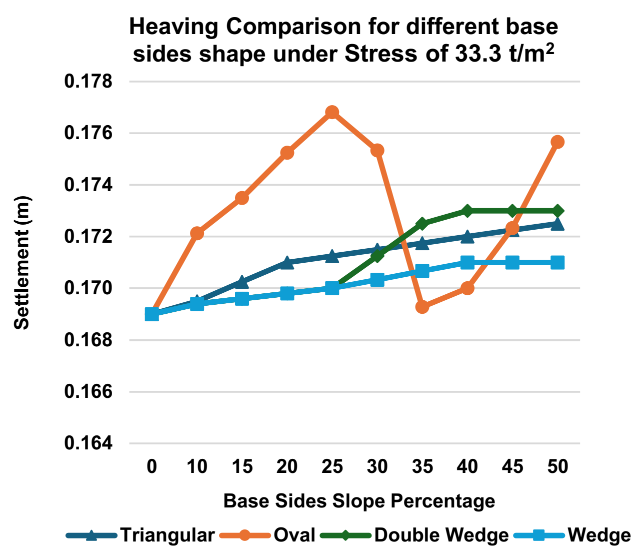


**Fig. 23** Relationship between base side slopes for different shapes and heaving curve with an applied stress of 33.3 t/m$^2$

stress equals 33.3 t/m$^2$ then the double wedge base shape then e oval and the wedge shape has the least settlement values.

Also, double wedge and oval have so much similar settlement values.

### 3.4.2 For heaving at certain stress

**3.4.2.1 Under stress of 11.1 t/m$^2$** Figure 21 shows that the triangular foundation base shape heaves most with a stress of 11.1 t/m$^2$ and with the highest rate of increase while increasing base side slope percentage then the double wedge base shape with less increase rate while increasing base side slope percentage then oval and the wedge shape has the least settlement values.

Also double wedge and oval have near values.

**3.4.2.2 Under stress of 22.2 t/m$^2$** Figure 22 shows that the double wedge foundation base shape heaves most with a stress equal to 22.2 t/m$^2$and with the highest rate of increase while increasing base side slope percentage then the triangular base shape and then oval foundation base shape that has the highest increase rate from 0 to 20% slope then heave decreased from 20 to 40% then it started to increase again

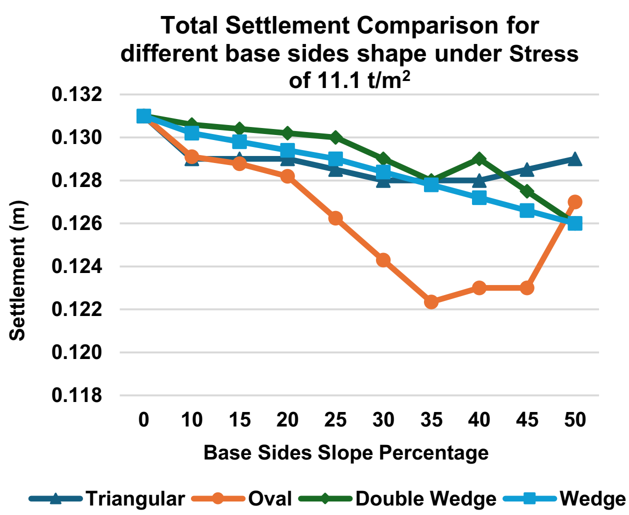


**Fig. 24** Relationship between base side slopes for different shapes and total settlement curve with applied stress of 11.1 t/m$^2$

until 50% and then the wedge shape has the least heaving values.

**3.4.2.3 Under stress of 33.3 t/m$^2$** Figure 23 shows that with a stress of 33.3 t/m$^2$ the oval foundation base shape has the highest increase rate from 0 to 25% slope then heave decreased from 25 to 35% then it started to increase again until 50% and it gave the highest heave values then the double wedge foundation base then the triangular base shape and the wedge shape has the least heaving values.

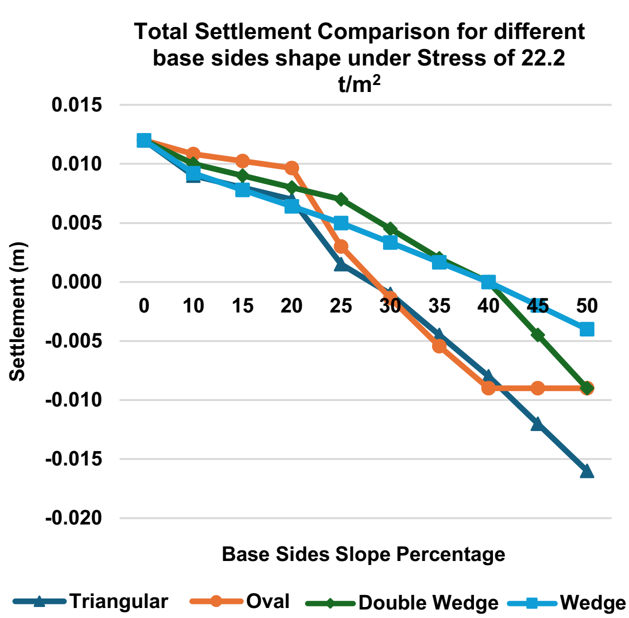


**Fig. 25** Relationship between base side slopes for different shapes and total settlement curve with an applied stress of 22.2 t/m$^2$

### 3.4.3 Total settlement at certain stress

**3.4.3.1 Under stress of 11.1 t/m$^2$** Figure 24 shows that under stress equals 11.1 t/m$^2$ for all foundation shapes with an increase of base side slopes the total settlement increases.

The oval foundation base shape has the highest increase rate (in settlement) and then the wedge foundation base shape then the double wedge foundation base shape and the triangular base shape have the least total settlement values.

**3.4.3.2 Under stress of 22.2 t/m$^2$** Figure 25 shows that under the stress of 22.2 t/m$^2$, all foundation shapes with an increase of base side slopes the total settlement increases.

The triangular foundation base shape has the highest increase rate (in settlement) then the oval foundation base shape then the double wedge foundation base shape and then the wedge base shape have the least total settlement values.

**3.4.3.3 Under stress of 33.3 t/m$^2$** Figure 26 shows that under a stress of 33.3 t/m$^2$, all foundation shapes with an increase of base side slopes the total settlement increases.

The triangular foundation base shape has the highest increase rate (in settlement) and then oval and double wedge foundation base shapes as they were near the wedge base shape have the least total settlement values.

## 4 Conclusion

1. the investigation into settlement behaviors across different foundation shapes—triangular, oval, wedge, and double wedge bases—reveals notable patterns influ-

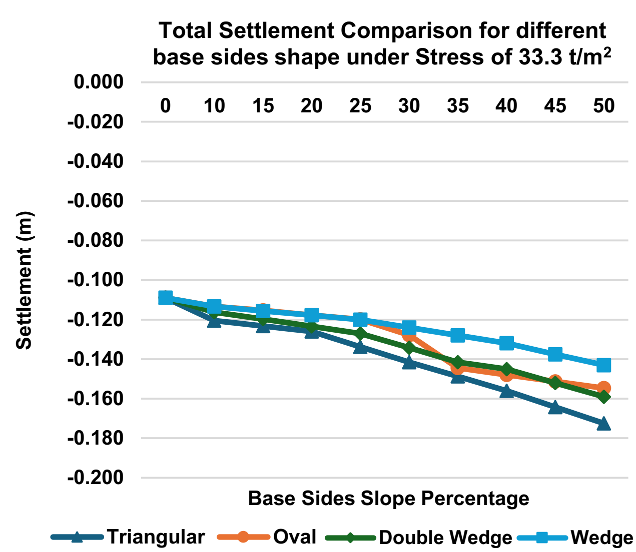


**Fig. 26** Relationship between base side slopes for different shapes and total settlement curve with an applied stress of 33.3 t/m$^2$

enced by applied stress and variations in base side slopes. For triangular, oval, wedge, and double wedge base foundations, settlements consistently increase with higher applied stresses and steeper side slopes, indicating the critical role of stress magnitude and base geometry in settlement behavior. Particularly noteworthy is the accelerated rate of settlements observed at a stress of 33.3 t/m$^2$ tons across all foundation shapes, suggesting a threshold effect where higher stress amplify settlement magnitudes disproportionately. These findings underscore the importance of considering both applied stress and base shape characteristics in foundation design and assessment to mitigate potential settlement issues and ensure structural integrity over time.

2. the analysis of various foundation shapes, including triangular, oval, wedge, and double wedge bases, reveals distinctive trends in heaving behavior under different applied stresses and alterations in base slope. For triangular base foundations, it's evident that heaving increases as the lower applied stress increases, with a slightly higher rate observed when altering the side slope, particularly for heavier stresses. Similarly, oval base foundations exhibit increased heaving with rising applied stresses, although alterations in side slopes have minimal impact. The trend persists for wedge and double wedge base foundations, where heaving escalates with increased stresses, and while adjustments in side slope don't significantly influence heave rates, there's a slight increase observed for certain stress levels. These findings underscore the importance of considering both applied stress and base shape characteristics in the design and assessment of foundations to mitigate potential heaving effects, The results suggest that the rate of heaving is more pronounced at higher stress levels, particularly for certain foundation shapes.
3. the comprehensive analysis of total settlement behaviors across various foundation shapes—triangular, oval, wedge, and double wedge bases—elucidates distinct trends influenced by applied stress and alterations in base side slopes. Across all shapes, for a stress of 11.1 t/m$^2$, heaving dominates over the settlement, resulting in an overall positive settlement. With increasing stress to 22.2 t/m$^2$, a transition phase is observed where heaving initially prevails, followed by a balance point where the foundation returns to its original position, and subsequently, a slight settlement emerges. Notably, for the highest stress of 33.3 t/m$^2$, settlement surpasses heaving, leading to an overall downward settlement trend. Furthermore, increasing the base-side slope ratio accentuates settlement tendencies. These findings underscore the intricate interplay between applied stress and base geometry in governing total settlement behavior, emphasizing the necessity for meticulous consideration of these factors in foundation design and assessment to ensure structural stability and longevity.
4. the data shows that the triangular foundation base shape settles the most under all three stresses of 11.1, 22.2, and 33.3 t/m$^2$, while the wedge shape has the least settlement values. The double wedge and oval shapes have similar settlement values, which are higher than the wedge shape but lower than the triangular shape. This comparison holds true for all three stresses.
5. the data analysis reveals that under a stress of 11.1 t/m$^2$, the triangular foundation base shape experiences the most heaving with the highest rate of increase, followed by the double wedge, oval, and wedge shapes. The double wedge and oval shapes show similar values in this scenario.

   Moving on to a stress of 22.2 t/m$^2$, the double wedge foundation base shape exhibits the most heaving with the highest rate of increase, followed by the triangular and oval shapes. The wedge shape has the least heaving values in this case.

   Lastly, under a stress of 33.3 t/m$^2$, the oval foundation base shape shows the highest increase rate in heaving from 0 to 25% slope, followed by the double wedge and triangular base shapes. The wedge shape has the least heaving values overall. These findings provide valuable insights into the behavior of different foundation base shapes under varying stresses and slope percentages.
6. the comparative analysis of different base side slope shapes under consistent stresses provides insights into their total settlement behaviors. For a stress of 11.1 t/m$^2$, it is observed that all foundation shapes experience increased total settlement with the rise in base side slopes, with the oval shape exhibiting the highest increase rate, followed by the wedge and double wedge shapes, while the triangular shape displays the least settlement values. Under a stress of 22.2 t/m$^2$, a similar trend is observed, with the triangular shape demonstrating the highest increase rate in settlement, followed by the oval, double wedge, and wedge shapes, which exhibit relatively lower settlement values. Similarly, under a stress of 33.3 t/m$^2$, all foundation shapes experience increased total settlement with increasing base side slopes, with the triangular shape showing the highest increase rate, followed closely by the oval and double wedge shapes, while the wedge shape exhibits the least settlement values. These findings underscore the importance of considering both stress magnitude and base side slope shapes in foundation design to mitigate total settlement issues and ensure structural stability and resilience.
7. Based on comprehensive comparative analyses and prior findings, it is evident that the Wedge Foundation configuration emerges as the most resilient form, effectively

mitigating soil swelling and yielding minimal total settlement. Following this, the oval foundation shape demonstrates a commendable performance, succeeded by the double wedge configuration. Conversely, the triangular base exhibits the highest degree of total settlement.

**Author contributions** I declare that I did all the work in this paper.

**Funding** No funding was received, I paid everything to do this work.

**Data Availability** The author confirm that the data supporting the findings of this study are available within the article and its supplementary materials.

## Declarations

**Conflict of interest** The author I declare that I have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.



## References

1. Nelson J, Chao K, Overton D, Nelson E (2015) Foundation engineering for expansive soils. Wiley, Hoboken
2. Chao KC, Nelson JD, Overton DD (2011) Factors influencing design of deep foundations on expansive soils. In: Proceedings of the 5th Asia Pacific conference on unsaturated soils, vol 2. Pattaya, Thailand, 14–16 November 2011, pp 829–834
3. Namdar A, Dong Y, Yin D (2019) The effect of concrete footing shape in differential settlement: a seismic design. Adv Civ Eng 1:1–8
4. Galindo R, Sanchez C (2012) A study of foundations on expansive soils. In: Proceedings of 2nd international conference on construction and building research, Valencia, Spain, 14–16 November 2012, pp 479–486
5. Rangel H et al (2011) 3D Analysis of an irregular-geometry foundation under the effects of an expansive soil. Int J Sci Technol 4(8):30884
6. PLAXIS 3D. https://www.geoengineer.org/software/plaxis-3d. Accessed 24 May 2022
7. Abas HA (2020) A numerical study of strip footing with granular pile anchor build on expansive soils, Wad Medani City—Sudan. Int Res J Innov Eng Technol (IRJIET) 4(10):1–6
8. Sangeetha S, Krishna PH (2020) Analysis of heave behavior of expansive soil provided with granular pile anchors using plaxis. Advances in computer methods and geomechanics. Springer, Singapore, pp 391–404
9. Abbas HA (2019) Numerical model of stone column in Sabkha soil. Int Res J Innov Eng Technol (IRJIET) 3(9):8–11
10. Abas HA (2021) Deformation of trapezoidal hydraulic canal constructed on expansive soils: a numerical study. Am J Eng Res (AJER) 10(10):01–05