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Research Article

Numerical Approach to Appreciate the Interaction of Two Neighbouring Shallow Foundation on a Cohesive and Partially Cohesive Soil

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Abstract

The program (cast3m) produced for us tables of values of stresses, displacements, images characterising stresses, displacements and deformations with their corresponding graphs. The results were presented as part of this study. It has been found that: two shallow closed foundations seriously affect the soil between them regardless of the soil type. Then, when the foundation is at same level in the different soil type and stress values are extracted in the zone of the cohesive soil (soft clay). A horizontal separation to width of foundation ratio was 0.7 and an influence equation was 0.333 if values of stresses are extracted from the partially cohesive soil (sandy clay). As per the vertical variation of the foundation in the different soil type. Independent of the soil type and the depth variation, a vertical separation to width of foundation ratio of 0.333 was observed. As the cohesion increases, the soil becomes denser which account for the high limit compressive stress compared to inferior values of cohesion. Finally, it is seen as a result of this research that the type of soil has a great rule to play as far as the interaction between two foundations is concern. An interaction led to failure when the foundation had a vertical gap between it that did not meet the above equation.

Keywords

Numerical Approach, Interactions, Shallow Foundations, Cohesion, Soil

1. Introduction

A foundation said to be shallow is defined as a structure with depth equal to 3 to 4 times the width of the foundation that transmit imposed loads into the ground, very near to the surface rather than the lower layers of the earth [1-3]. In the domain of foundation engineering, studying interaction between two neighboring shallow foundation has a great place in the heart of scientific advancement in order to overcome problems associated with the foundation and the environment (soil) [4]. Nu-

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merical approaches play a crucial role in understanding and analyzing the interaction between neighboring shallow foundations on cohesive and partially cohesive soils. This topic is of great importance in geotechnical engineering, as it helps engineers design and assess the stability and performance of foundation systems. When two or more shallow foundations are built in close proximity, their loadings can interact with each other, leading to changes in soil stresses and settlements [5, 6]. This interaction becomes even more complex when the soil is cohesive or partially cohesive, as these types of soils exhibit different behaviors compared to cohesion less soils. To appreciate this interaction, numerical methods such as finite element analysis (FEA) or finite difference method (FDM) are commonly used. These methods involve dividing the soil and foundation systems into smaller elements or grids and solving mathematical equations to simulate the mechanical behavior of the soil and foundations under various loading conditions.

Stuart show that the interactions between footings in cohensionless soil on the base of the limit equilibrium method [4, 7], his experiment agrees with Terzaghi's formular. West and Stuart show that the method of stress characteristics to establish a solution for the interference of a strip footing on sand soil [8-10], their outcomes showed that the efficiency factor (ξ) values were smaller compared to those obtained by Stuart. Selvadurai and Rabbaa show that the interference of three closely spaced strip foundations on Ottawa and silica sand [11], interference initiated when spacing is of ratio $S/B < 3$. Graham show that the interference of three closely spaced strip foundations on Ottawa and silica sand [12, 13], the interaction depends on soil friction angle and efficiency factors for versus spacing are given. Lee and Eun show that studying of interference of footing using conducted field circular plate test [14], conducted field circular plate test. Failure stress of the soil beneath neighbored footing is higher than isolated footing; however, larger settlements occurs beneath neighbored footing [10]. Srinivasan and Ghosh show that laboratories scaled model tests of circular footings in dry dense homogeneous sand [15], concluded that efficiency factors (ξ) are found to be maximum at S/B = 0.5. Reddy. Borzooei, and Reddy show that test on Square and circular footing model On Medium dense sand, square and circular footing model were conducted. On sand, the closeness of footings found to improves the responses of foundations both in terms of settlement and ultimate bearing capacity; nevertheless, increasing in settlements are being observed at between B ≤ S ≤ 6B. Srinivasan and Ghosh show that investigation on two layers of sand (weak layer underline by strong layer) [16], they reached the following conclusion that the bearing capacity and the developed settlement at failure declined with an increase in the depth of the upper weak layer. Efficiency factors (ξ) are found to be maximum at S/B = 0.5. All previous research studies explored the effect of the interaction of closely spaced shallow foundations on the bearing capacity at the ultimate failure compared to the settlement behavior which is for some reason not addressed profoundly, even though it is more critical than bearing capacity.

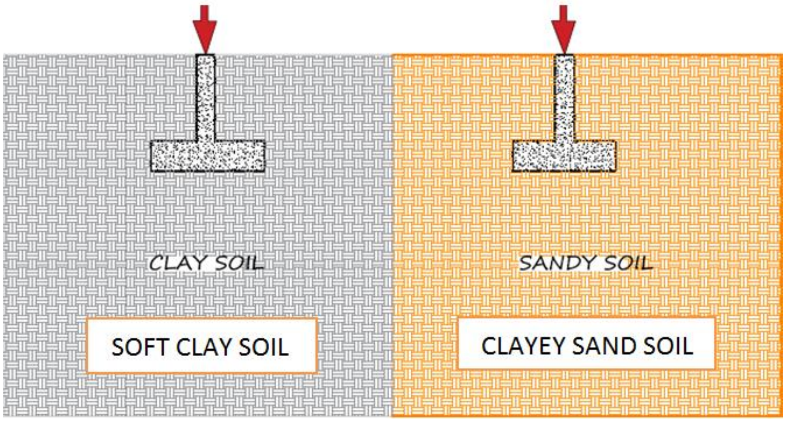


Figure 1. *Presentation of the geometry of the foundations in the different soil.*

The main objective is to accurately predict the effects of interaction, including changes in soil stresses, settlements, and potential failure mechanisms. By doing so, engineers can make informed design decisions to mitigate risks and ensure the stability and performance of the foundation system. Addressing this problem requires the development and implementation of numerical techniques, such as finite element analysis (FEA) or finite difference method (FDM), that can simulate the behavior of the soil-foundation system under various loading conditions. These techniques should be able to capture the complex behavior of cohesive and partially cohesive soils and provide reliable predictions of the interaction between neighboring shallow foundations. Overall, the problem statement revolves around developing a numerical approach that can effectively analyze and appreciate the interaction between neighboring shallow foundations on cohesive and partially cohesive soils, leading to improved design practices and safer structures. Figure 1 show the geometry of the foundations in the different soil.

2. Materials and Method

2.1. Method

As part of this research, a numerical approximation of the behavior model of two neighboring shallow foundations in a cohesive and partially cohesive soil has been proposed. CAST3M software as the numerical tool was used.

CASTEM is a computer code for the analysis of structures by finite element method. CASTEM presents a complete system, integrating not only the functions of calculation themselves, but also the functions of constructing models (preprocessor) and processing the results (post-processor). CASTEM made it possible for us to deal with problems of linear elasticity in the statics and dynamics fields (extraction of eigenvalues), nonlinear problems (elasto-viscoplasticity), step by step dynamic problems, etc [17]. In order to convert the names of the objects into data-processing entities usable by the program, it is necessary to have an interface. It is the GIBIANE language which will make it possible for us to communicate directly with the program [18].

2.1.1. Presentation of Model

Physical geometry

Three models characterized this study: the two foundations were placed at the same level, a vertical variation of the right foundation was made while fixing the left foundation and vice versa. Figure 2 below show case 1 of the foundations placed at the same level and Figure 3 below show case 2 of the vertical variation of the right foundation.

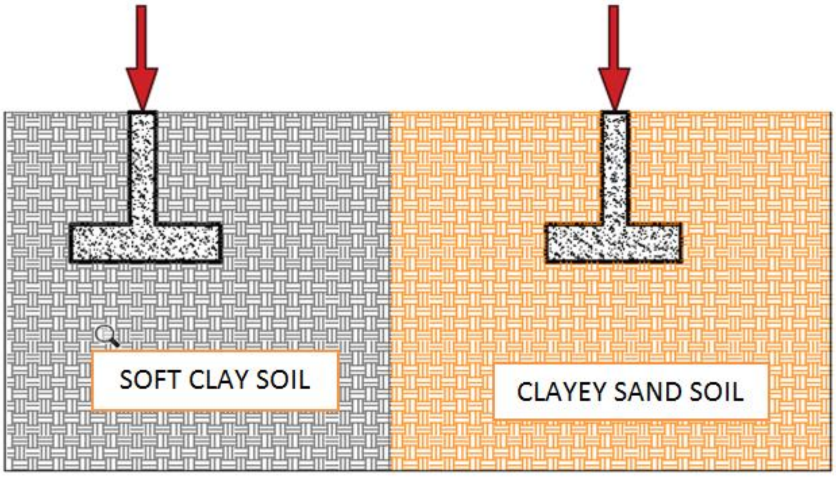


Figure 2. *Case 1: Foundations placed at the same level.*

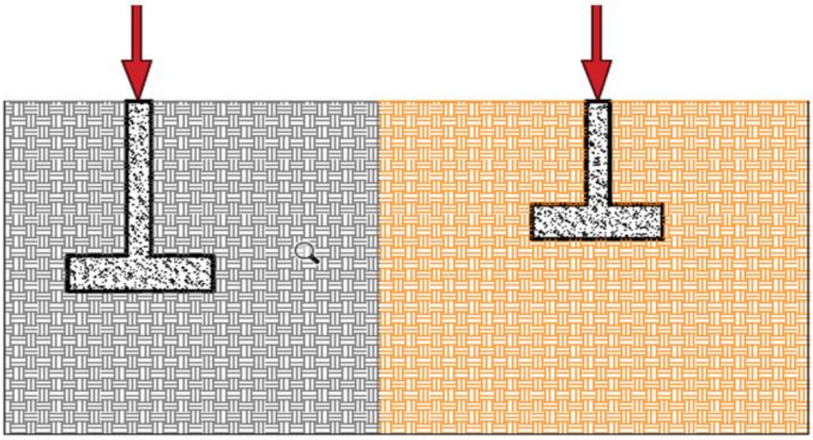


Figure 3. *Case 2: Vertical variation of the right foundation.*

2.1.2. Boundary Conditions

The limit conditions for the modelling of this two shallow foundations are attached to the geometry of the model. The foundation is in contact with the foundation soil. From the geometry below:

CL1 = BLOQ DEPLA ROT (L1 ET LPP55); the base of the foundation is rigid.

CL2 = BLOQ UX L20; the soil on the adjacent sides do not move in the horizontal direction.

CL3 = BLOQ UX L2; the soil on the adjacent sides do not move in the horizontal direction.

CL4 = BLOQ UY (L26 ET L35); the footing is rigid compared to the soil and thus does not change in shape horizontally.

The Figure 4 below show the geometry of the boundary conditions.

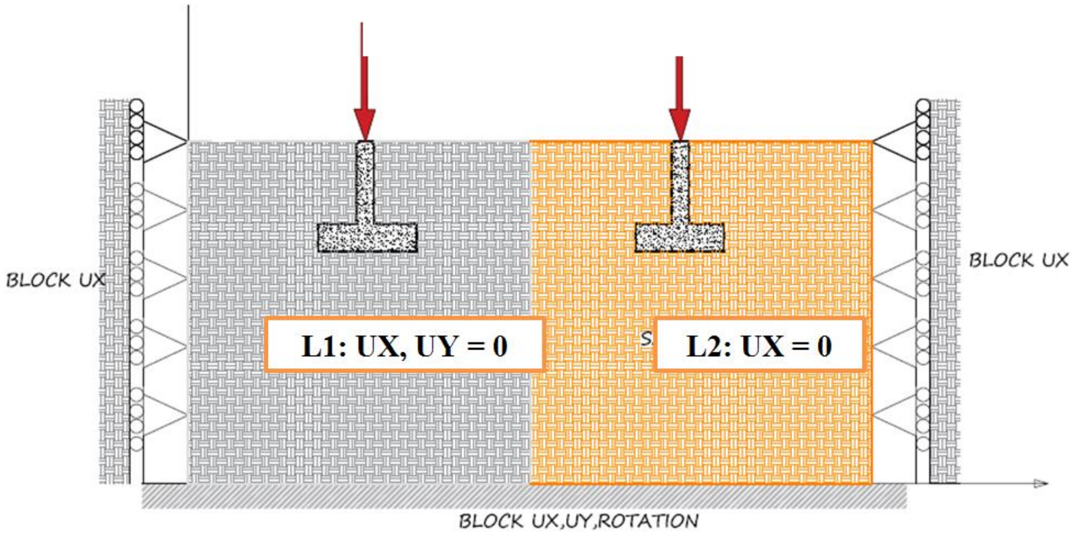


Figure 4. *Geometry of the boundary conditions.*

2.2. Mechanical Characteristics

2.2.1. Behavioral Law

Figure 5 show the three sub-behavioral laws: Concrete, Soil and Interface.

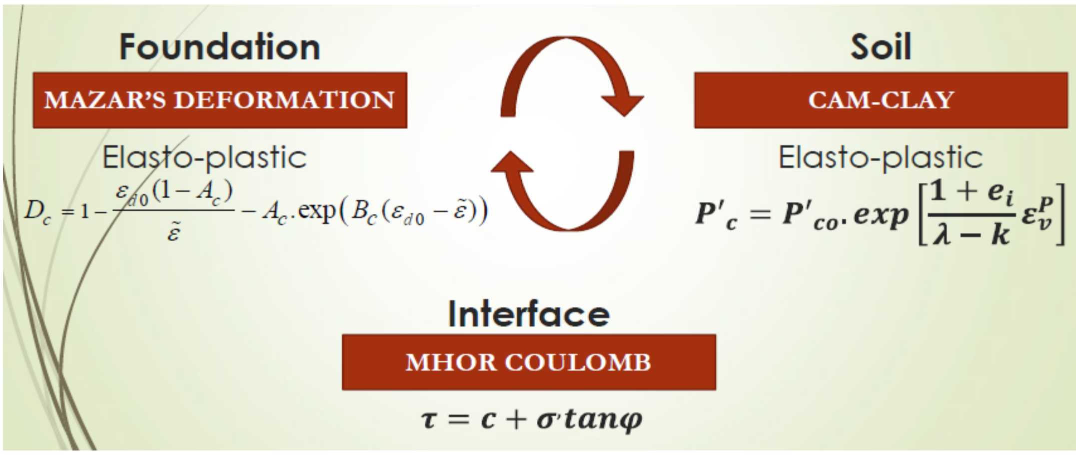


Figure 5. *Three sub-behavioral laws: Concrete, Soil and Interface.*

The table 1 show the foundation (concrete) characteristics of Mazar's deformation model.

Table 1. Foundation (concrete) Characteristics of Mazar's deformation model [19].

PARAMETERS	SYMBOL	NUMERICAL VALUE
Young's Modulus	E (Mpa)	27000
Volumic mass	$\rho\ (Kg/m^3)$	2500
Poisson's Ratio	ϑ	0.2
Thresholddeformation in tension	$KTRO$	1×10^{-4}
Compression Parameter	$ACOM$	1.4
Compression Parameter	$BCOM$	1900
Tension Parameter	$ATRA$	0.8
Tension Parameter	$BTRA$	17000
Correction parameter for shearing	$BETA$	1.06

2.2.2. Characteritics

Tables 2, 3 and 4 show respectively the characteristics of soft clay soil of Douala, characteristics of clayey sand soil of Douala, Concrete-Soil Interface Characteristics.

Table 2. Characteristics of soft clay soil of Douala.

PARAMETERS	SYMBOL	NUMERICAL VALUE
Young's Modulus	E (Mpa)	24
Volumic mass	$\rho\ (Kg/m^3)$	1575
Poisson's Ratio	ϑ	0.43
Indice of voids	EO	0,37
Coefficient of Friction	M	0.6
Internal angle of friction	φ	30
Cohesion	$COHE$ (KPa)	40
Pre-consolidation pressure	PO (KPa)	20
Elastic slope	$KAPA$	0.02
Plastic slope	$LAMD$	0.1
Shear Modulus	$G1$ (MPa)	15.4

Table 3. Characteristics of clayey sand soil of Douala.

PARAMETERS	SYMBOL	NUMERICAL VALUE
Young's Modulus	E (Mpa)	16
Volumic mass	$\rho\ (Kg/m^3)$	1900
Poisson's Ratio	ϑ	0.286
Indice of voids	EO	0,33
Coefficient of Friction	M	0.9

PARAMETERS	SYMBOL	NUMERICAL VALUE
Internal angle of friction	φ	10
Cohesion	$COHE$ (KPa)	25
Pre-consolidation pressure	PO (KPa)	30
Elastic slope	$KAPA$	0.02
Plastic slope	$LAMD$	0.1
Shear Modulus	$G1$ (MPa)	10.3

Table 4. *Concrete-Soil Interface Characteristics [15].*

PARAMETERS	SYMBOL	NUMERICAL VALUE
Second Normal stiffness constant	EF	$2 \times 10^{15} N/m^2$
Threshold deformation	ECN	1000%
Cohesion	COHE	10kPa
Angle of friction	FRIC	20
Maximum resistance in tension	FTRC	0

A load intensity of 50KN was applied. This loading was done following the Cast3m operator: PASAPAS, which takes into consideration time as a parameter. Figure 6 show load factor-time graph.

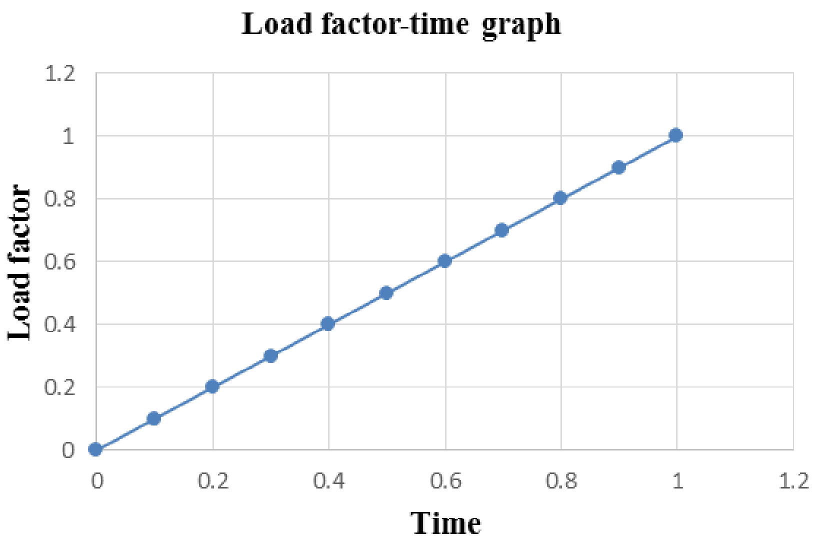


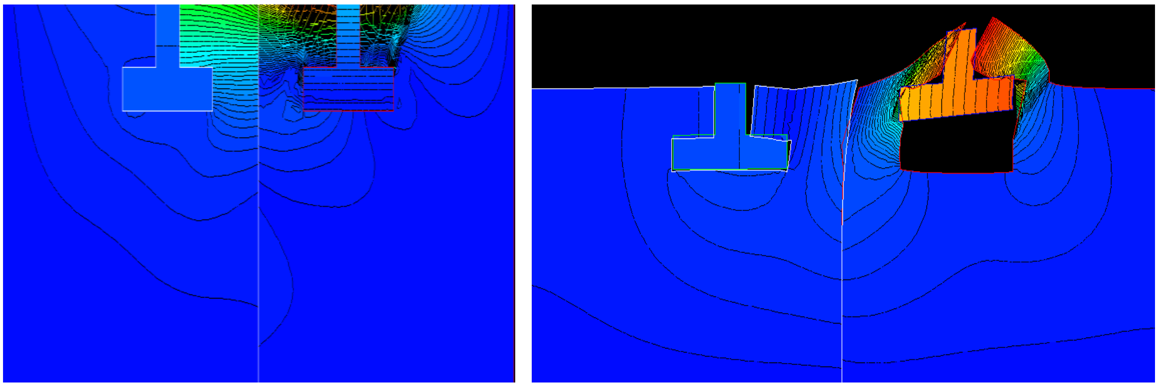
Figure 6. *Load factor-time graph.*

3. Result and Discussion

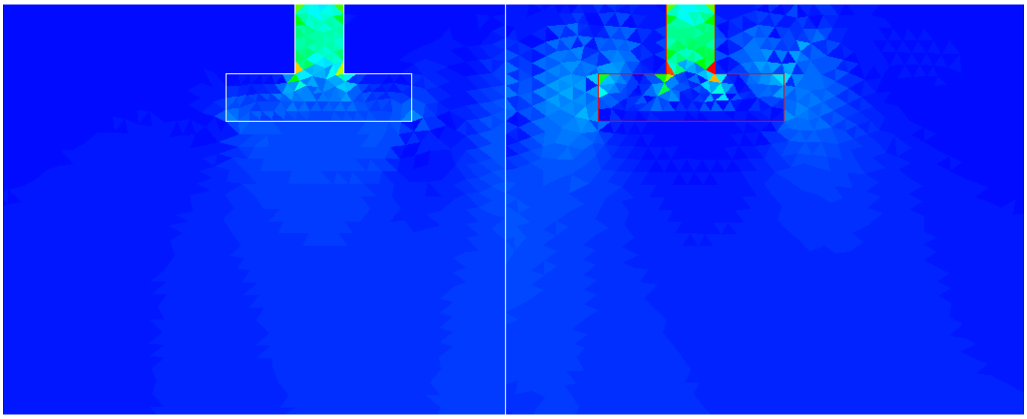
For the different cases, stress-displacement graphs and space-stress separation graphs, separation-settlement space graphs were observed. Images of horizontal displacement, vertical displacement (subsidence) and vertical stress were observed. The Figure 7. pictures of XX displacement, deformation, stress for case 1.

3.1. Case 1; Foundations Placed at the Same Level

DETA-X = 1m DETA- Y = 0



Horizontal displacement Vertical deformation



Vertical stresses in the soil

Figure 7. *Pictures of XX displacement, Deformation, Stress for case 1.*

Commentary on foundation in soft clay (silty clay) influence by clayey sand (clay loam) soil with variation of the horizontal gap between them.

Extraction of values in soft clay soil

Figures 8 and 9 show the settlement-space separation graph and stress-space separation graph for case 1.

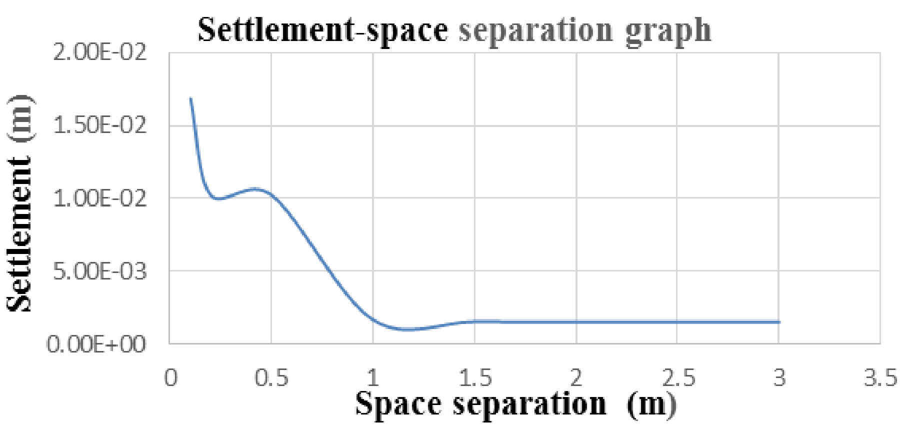


Figure 8. *Settlement-Space Separation Graph for Case 1.*

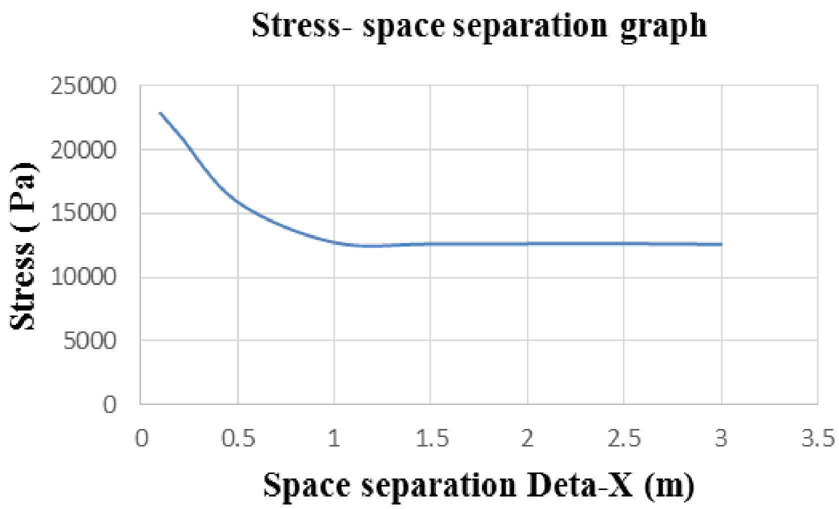


Figure 9. Stress-Space Separation Graph for Case 1.

1. From the mid-stress-strain graph, stress-space separation graph, settlement-space separation graph, as the space separation increases the settlement under the left footing decreases and becomes constant, while the stress decreases and becomes constant.
2. From the settlement-space separation graph, a monotonous interaction but all leading to a decrease of settlement at increasing space separation and further reaches a constant zone. This monotonous decreasing zone is delimited by a space separation of 1 meter.
3. Mathematically, from graph, the threshold value of space separation is 1meter, hence a fractional empirical equation as shown below.

$$\frac{Sh}{B} \geq \frac{2}{3} \sim 0.7 \quad (1)$$

Sh = horizontal space separation between two foundation (m)

B = the base of the foundation in the soil in consideration (m)

Where S is the gap between two foundations and B: the base of the footing. This expression above translates the threshold space separation above which settlement of two neighbouring shallow foundations in a soft clay –Clayey sand taking into consideration the soft clay soil.

Extraction of values in clayey sand soil

Figures 10 and 11 show the settlement-space separation graph and the stress-space separation graph for case 1.

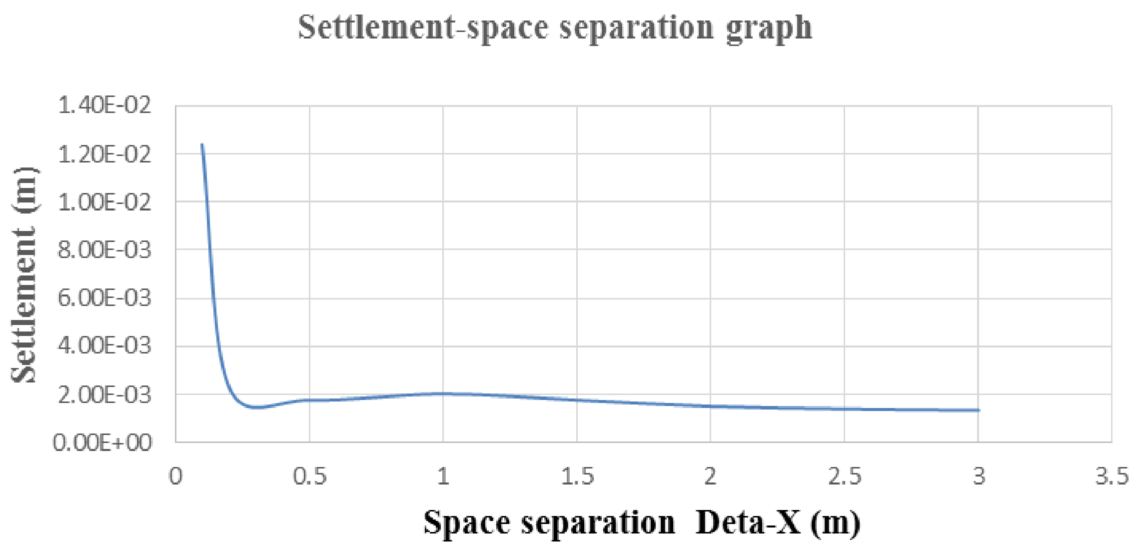


Figure 10. Settlement -Space Separation Graph for Case 1.

Figure 11. *Stress-Space Separation Graph for Case 1.*

3.2. Case 2 Vertical Variation of Right Footing While Fixing Left Footing

The Figure 12 below show the Pictures of XX displacement, Deformation, Stress for Case 2.
DETA-Y = 1m, DETA-X = 0.1m
HORIZONTAL DISPLACEMENT VERTICAL DEFORMATION

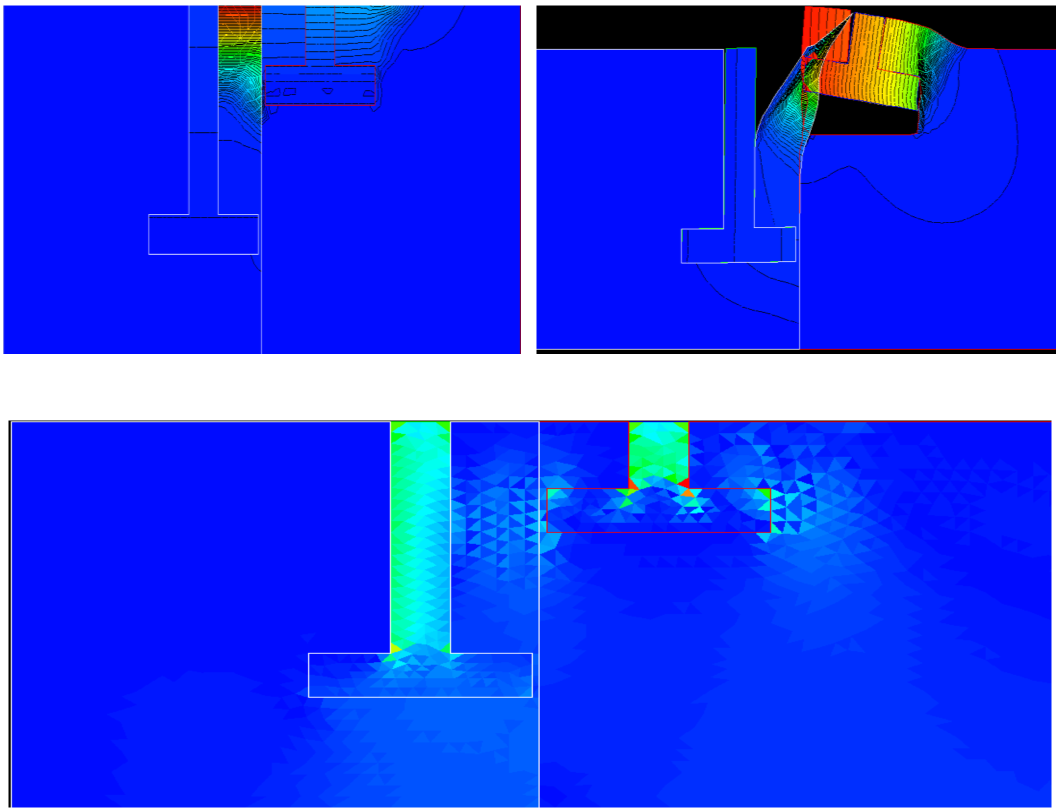


Figure 12. *Pictures of XX displacement, Deformation, Stress for Case 2.*

From the Stress-strain Graph, clayey sand soil under the foundations, follows respects the Terzaghi soil deformation curve indispensable of the different space separations.

From the Maximum Stress-Space Separation Graph, the stress in the soil between both foundations decreases and attains a threshold value 0.5meter then becomes constantly monotonous.

The mathematical expression of this behavior can be expressed by the inequality below:

$$\frac{Sh}{B} \geq \frac{1}{3} \sim 0.333 \qquad (2)$$

The expression above, gives the threshold space separation above which there is least stress interaction between both foundations.

S = horizontal space separation between two foundation (m)

B = The base of the foundation in the soil in consideration (m)

Where S is the gap between two foundations and B: the base of the footing. This expression above translates the threshold space separation above which settlement of two neighbouring shallow foundations in a soft clay –Clayey sand taking into consideration the clayey sand soil.

Extraction of values in soft clay soil

Figures 13 and 14 show the combined maximum settlement-vertical position graph and combined maximum mid stress-vertical position graph.

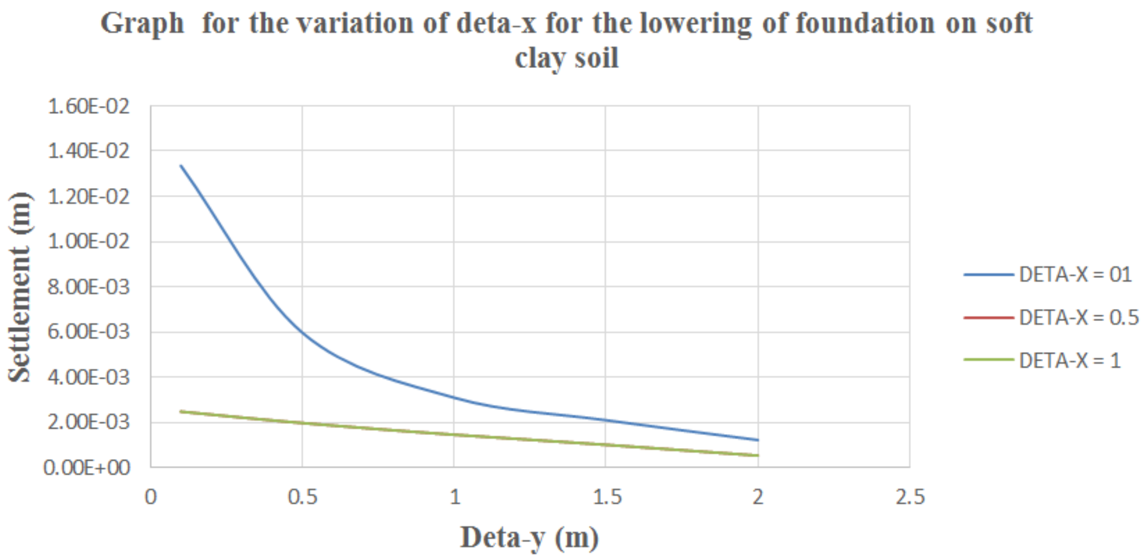


Figure 13. *Combined Maximum Settlement-Vertical Position Graph. Case 2 (delta-x = 0.1, 0.5, 1).*

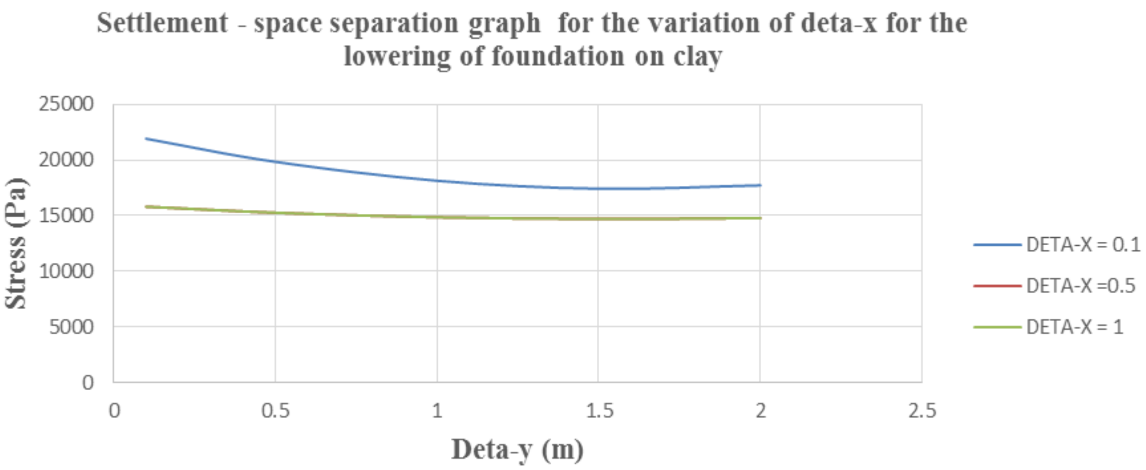


Figure 14. *Combined Maximum Mid Stress-Vertical Position Graph. Case 2 (delta-x = 0.1, 0.5, 1).*

1. The combined Settlement-Vertical position graphs and Stress-Vertical Position graphs clearly interprets to us the various Mid Stress-strain graphs:
2. From these combined graphs that, as the vertical position of the right footing increases, there is a decrease in the settlement and Stress under the left footing. This ratio of decrease, becomes significantly very small as the horizontal gap between both foundations increase.

This phenomenon becomes constant for a Horizontal space separation of 0.5m.

The mathematical expression of this behavior can be expressed by the inequality below:

$$\frac{Sv}{B} \geq \frac{1}{3} \sim 0.333 \quad (3)$$

The expression above, gives the threshold space separation above which there is least stress interaction between both foundations.

Sv= vertical space separation between two foundation (m)

B = the base of the foundation in the soil in consideration (m)

Extraction of values in clayey sand soil

Figures 15 and 16 show the combined maximum settlement-vertical position graph and Combined maximum stress-vertical position graph for case 2.

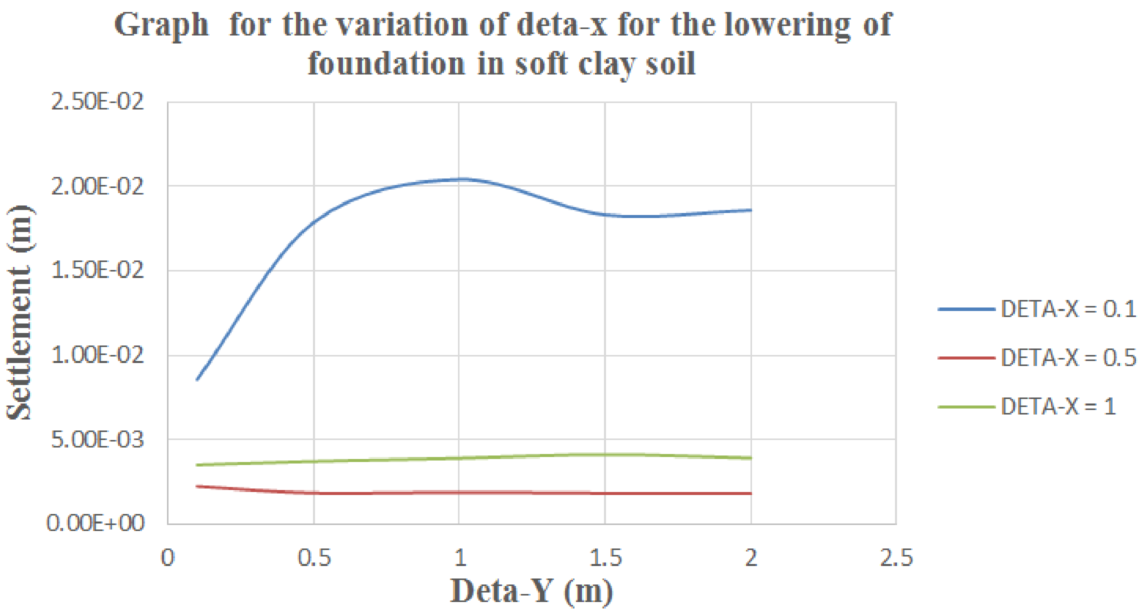


Figure 15. Combined Maximum Settlement-Vertical Position Graph. Case 2 (Delta-x = 0.1, 0.5, 1).

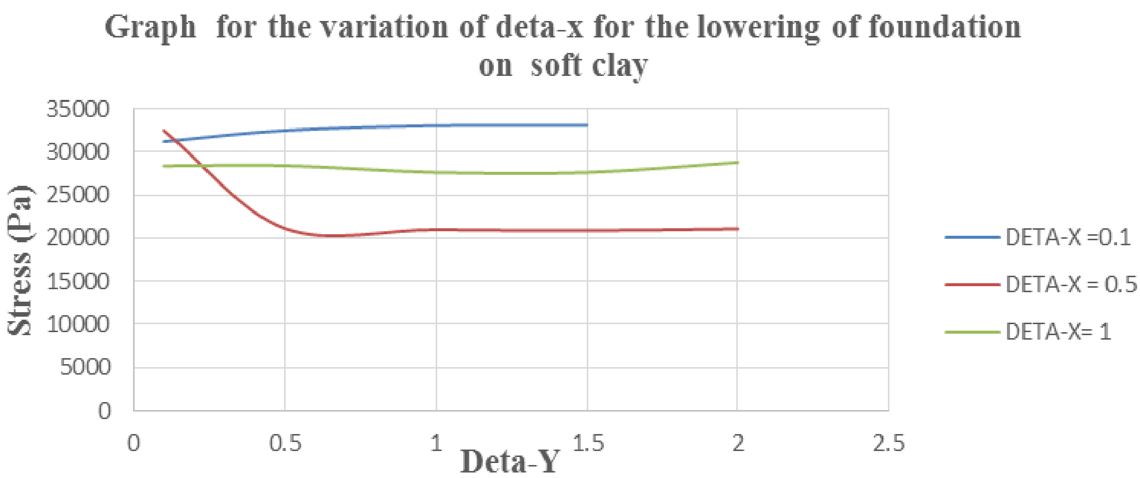


Figure 16. Combined Maximum Stress-Vertical Position Graph. Case 2 (Delta-x = 0.1, 0.5, 1).

1. It is observed that for a very small separation, Stress increases as the depth of the right foundation increases and becomes constants at a vertical difference of 0,5m;
2. One equally observe that the maximum settlement of the clayey sand soil occurs at a depth of 1meter
3. The mathematical expression of this behavior can be expressed by the inequality below:

$$\frac{Sv}{B} \geq \frac{1}{3} \sim 0.333 \quad (4)$$

The expression above, gives the threshold space separation above which there is least stress interaction between both foundations.

Sv = vertical space separation between two foundation (m)

B = the base of the foundation in the soil in consideration (m)

Influence of cohesion on the settlement of the soft clay soils.

Figures 17 and 18 show the graph of settlement against cohesion and graph of stress against cohesion.

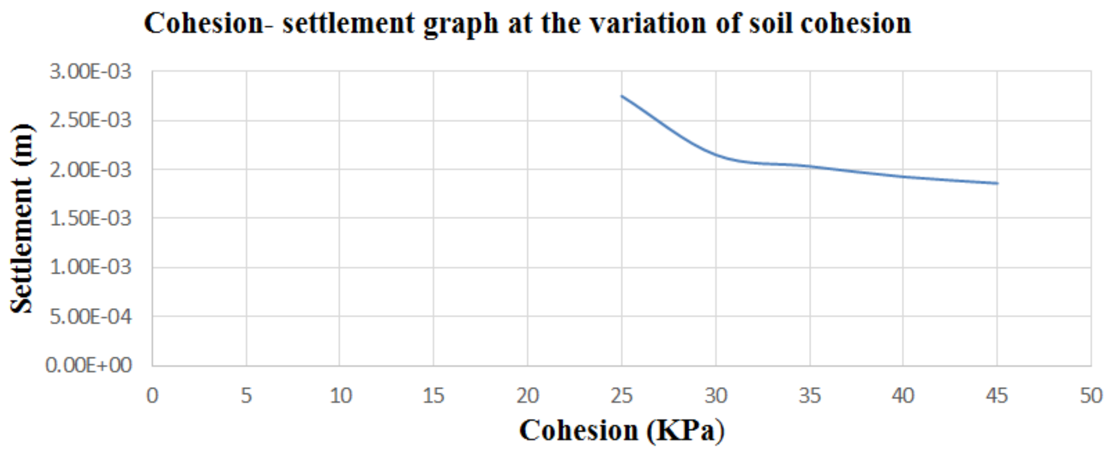


Figure 17. Graph of Settlement against Cohesion.

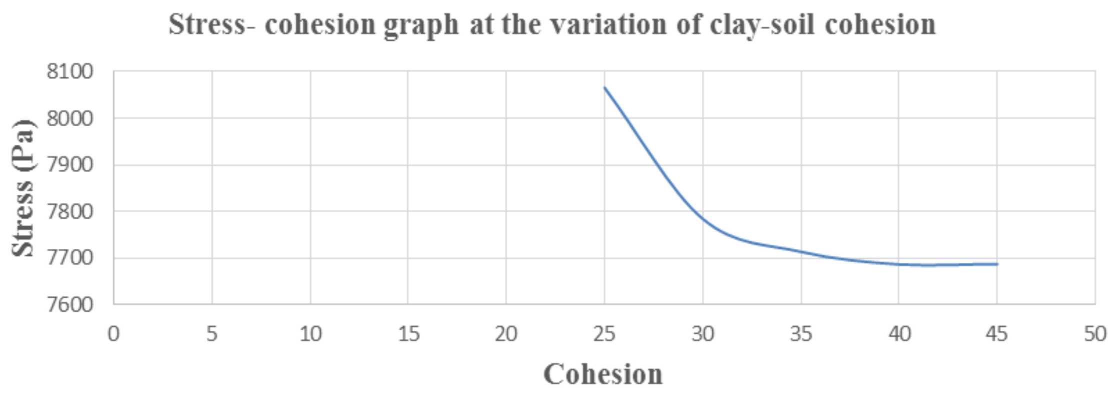


Figure 18. Graph of Stress against Cohesion.

Influence of cohesion on the settlement of the sandy-clay soils.

Figures 19 and 20 show the graph of settlement against cohesion and graph of stress against cohesion.

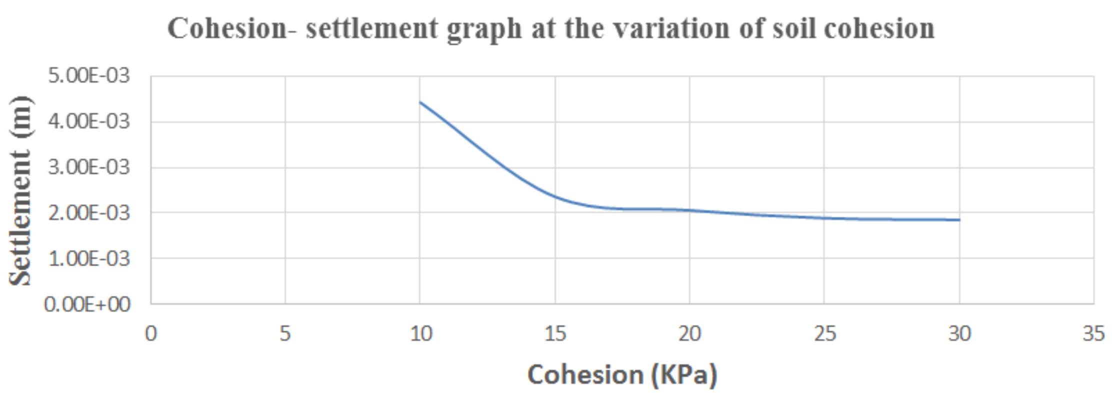


Figure 19. Graph of Settlement against Cohesion.

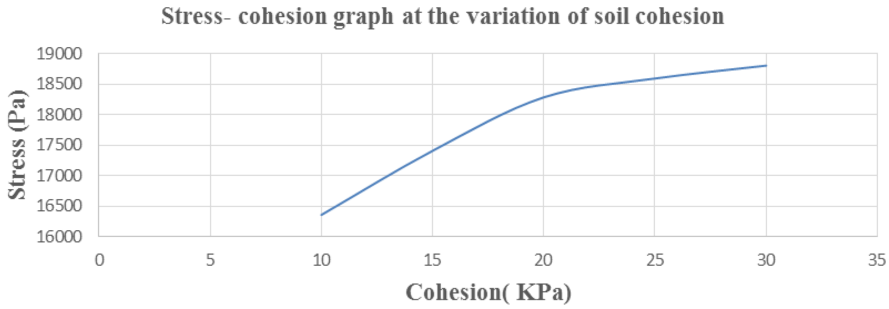


Figure 20. *Graph of stress against cohesion.*

From the Graphs above that, as the Cohesion increases, the settlement under the footings decreases. This explains that, the soil becomes more rigid and resistant to settlement as the cohesion of the soil increases.

4. Conclusions

The results of simulation were showed that closely spaced shallow foundations in a Sandy Clay soil interact greatly. The spacing between neighboring shallow foundations has been identified as a critical factor influencing the interaction. Smaller spacing leads to increased soil stress concentrations and higher settlements between foundations. The presence of cohesion in the soil has been found to significantly affect the interaction between neighboring shallow foundations. Cohesive soils tend to transfer more load between neighboring foundations, resulting in higher soil stresses and settlements. Soil-structure interaction has been considered in numerical analyses to improve the accuracy of predicting the behavior of neighboring shallow foundations on cohesive and partially cohesive soils. This includes accounting for the interaction between the foundations and the surrounding soil. The numerical approach has proven to be a valuable tool for designing and optimizing neighboring shallow foundations on cohesive and partially cohesive soils. It allows for better understanding of the interaction behavior and can lead to more efficient and cost-effective foundation designs. Shallow foundations on cohesive and partially cohesive soils and have highlighted the importance of considering the interaction effects in design and analysis. However, further research is still needed to explore additional factors and refine the numerical approaches used in evaluating this interaction.

Abbreviations

FEA	Finite Element Analysis
FDM	Finite Difference Method
Cast3M	Castem

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Author Contributions

Kuma Moses Mbuh initiated the project and project administration, investigation and writing-original draft; Leonard Nsahlai and Penka Jules Bertrand: Supervision, formal analysis, validation, writing review and editing; Arnaud Nguessi Kouamou: Methodology, Data curation, Visualization, writing review and editing; Elvis Agandeh and Abong Claret Phonchu: read and approved the final manuscript.

Conflicts of Interest

The authors declare no conflicts of interests.

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