World Journal of Advanced Research and Reviews
eISSN: 2581-9615 CODEN (USA): WJARAI
Cross Ref DOI: 10.30574/wjarr
Journal homepage: https://wjarr.com/

(Research Article)

Simulative study of the interactions between two neighboring shallow foundations

Mbuh Moses Kuma [1,*], Nsahlai Leonard [2], Penka Jules Bertrand [2], Kouamou Nguessi Arnaud [1,*], Tchemou Gilbert [3], Agandeh Elvis [1] and Phonchu Claret Abong [2]

[1] *Department of Civil Engineering and Forestry Techniques, Higher Technical Teacher Training College, University of Bamenda, Cameroon.*
[2] *Department of Civil Engineering and Architecture, National Higher Polytechnic Institute (NAHPI), University of Bamenda, Cameroon.*
[3] *Department of Civil Engineering, Higher Technical Teacher Training College, University of Douala, Cameroon.*

World Journal of Advanced Research and Reviews, 2025, 26(03), 1794-1805

Publication history: Received on 19 April 2025; revised on 25 May 2025; accepted on 27 May 2025

Article DOI: https://doi.org/10.30574/wjarr.2025.26.3.0675

Abstract

Foundations are designed to receive both imposed loads and superimposed loads and evenly distribute these loads to the bearing soil. Construction of load bearing elements can necessitate that two shallow foundations should have a close proximity. This close proximity gives birth to interactions studied numerically in this article. This study investigates the influence of horizontal and vertical space separation on the settlement of the foundations in soft clay soil. In this study, the Numerical method of research Cast3m was used. A geometrical model with mechanical characteristics to translate exactly a real case was built. At the end of the simulation, the space separation versus settlement behavior followed an exponential increase whereby, beyond a space separation to base ratio greater than or equal to 0.7 there was no interaction. The closer the two foundations, the more the horizontal displacements at the extremities of both foundations-both foundations tend to function like a single footing when they are closely spaced. This study is a breakthrough in foundation interactions for the case of clay soil as many researchers have concentrated their studies on sandy soil. Civil Engineers, Architects should consider the effect of space separation influence carried out in this study when doing conception and analysis of structures.

Keywords: Simulation; Space Separation; Settlement; Interactions; Shallow Foundations; Stresses

1. Introduction

A foundation is that part of a structure that receives loads and evenly distributes it to the bearing soil. Foundations placed at very close proximity experience interactions which can engender various behaviors. Studying interaction between two neighboring shallow foundation is a great scientific advancement in foundation engineering in order to overcome problems associated with the foundation and the environment (soil). The safety of a foundation and the soil beneath it, totally depends on the factors taken into consideration before and after the realization. The advantage of taking into consideration the interaction between two neighboring shallow foundation includes; maximizing space separation between foundations, excess stresses and settlement.

The concept of interaction between two neighboring foundation was first visited by Stuart on the effect of closely continuously spaced foundations [1]. West and Stuart applied the method of stress characteristics to establish a solution for the interference of a footing on sand soil [2]. Their outcomes showed that the efficiency factor (ξ); which is a function of spacing to width of the foundations and soil friction angle values were smaller compared to those obtained by Stuart [2]. The downside of their research is that they only configure a solution for a soil having friction angle of 35°. Selvadurai and Rabbaa [3] investigated the interference of three closely spaced strip foundations on Ottawa and silica sand and

* Corresponding author: Mbuh Moses Kuma and Kouamou Nguessi Arnaud.

Copyright © 2025 Author(s) retain the copyright of this article. This article is published under the terms of the Creative Commons Attribution License 4.0.

came out with the conclusion that; interference initiated when spacing is of ratio $S/B < 3$, where B is the base of the foundation and S, the space separation between the two foundations [2],[3]. Furthermore, Graham et al. [4] investigated the interference of three closely spaced strip foundations on Ottawa and silica sand using the same method suggested by West and Stuart [2]. The results show that the method of stress characteristics is applied to designate the interference of the outer foundations on the bearing capacity of the central footing and it is not a suitable theory for two closely spaced footings. This may justify why West and Stuart obtained lower efficiency factors (ξ). The result given by Graham et al [4] was that, the interaction depends on soil friction angle and efficiency factors versus spacing as given by [4], [5]. Kumar and Ghosh provided the failure mechanisms beneath two rigid continuous foundations which coincided well with the assumption of Stuart [6]. Moreover, several types of research are reported on the bases of analytical approach, probabilistic approach, and upper bound limit analysis that the bearing capacity of neighbored foundation increases as the spacing between them is reduced [7]. Lee and Eun [8] carried out field circular plate test on sand and concluded that failure stress of the soil beneath neighboured footing is higher than isolated footing; however, larger settlements occur beneath neighboured footing. Srinivasan and Ghosh carried out several laboratories scaled model tests of circular footings in dry dense homogeneous sand and concluded that efficiency factors (ξ) are found to be maximum at S/B = 0.5 [9], with B as the base of the foundation and S the space separation between the two foundations. Reddy et al [14] carried their test on square and circular footing model on medium dense sand and they reached the conclusion that, the closeness of footings improve the response of foundations both in terms of settlement and ultimate bearing capacity; nevertheless, increase in settlements are being observed at between B ≤ S ≤ 6B. Srinivasan and Ghosh carried out their investigation on two layers of sand (weak layer underline by strong layer) and they reached the conclusion that, the bearing capacity and the developed settlement at failure declined with an increase in the depth of the upper weak layer and the efficiency factors (ξ) are found to be maximum at S/B = 0.5. [9] [10].

Against the above background, the main objective of this research was to study the mechanical behavior of soft clay soil between and beneath two neighboring foundations influenced by the load it receives and space separation (vertical and horizontal) between them and how to limit or reduce excessive soil stress and settlement.

2. Materials and method

2.1. Method

In the framework of this research, a numerical approximation to the behavior model of two neighboring shallow foundations in a soft clay soil was proposed. CAST3M software as numerical tool was adopted. CAST3M is a computer code for the analysis of structures by finite element method [15]. CAST3M 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) [15]. CAST3M 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 [15]. In order to convert the names of the objects into data-processing entities usable by the program, it was necessary to have an interface. It was the GIBIANE language which made it possible for us to communicate directly with the program [15].

2.2. Some features of the CAST3M software

2.2.1. Mesh Size

Mesh size is an essential aspect of CAST3M. The mesh size refers to the spatial discretization of the computational domain into smaller elements for performing numerical simulations. To affix a Mesh size in CAST3M you go by the word DENS and after that, you input the value you want. In the case of this paper, we used 0.25 as the mesh size**.** The Figure 1 below show the discretization of triangular shape of three nodes.

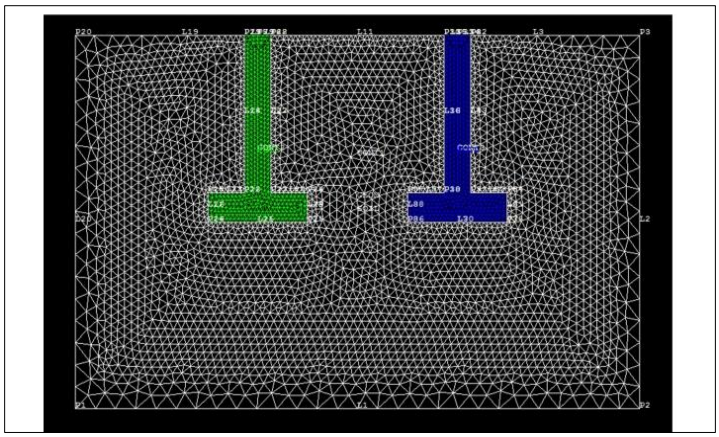


Figure 1 Discretization (meshing) of triangular shape of three nodes

2.2.2. Convergence

Convergence is the process of ensuring that the numerical solution obtained from iterative calculations approaches the correct solution as the computational process progresses.

2.2.3. Finite Element.

Triangular finite elements of three nodes were used.

2.3. Presentation of model

2.3.1. Physical geometry

Three models characterized this study: The two foundations were placed at the same level, then the right foundation was varied vertically while fixing the left foundation and vice versa. The Figure 2, 3 and 4 show the three models of study. (deta-x = horizontal space separation (m) , deta-y = vertical space separation (m)).

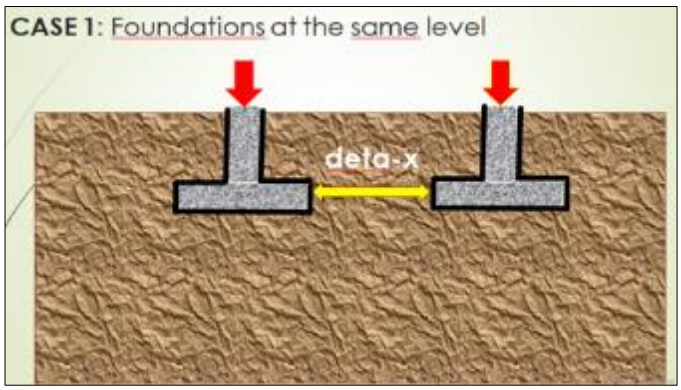


Figure 2 Foundations at the same level

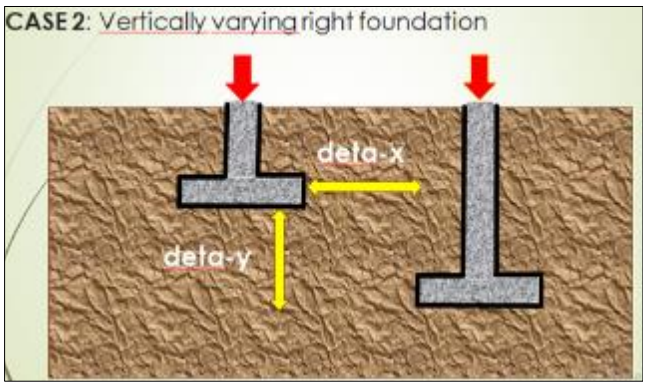


Figure 3 Vertically varying right foundation

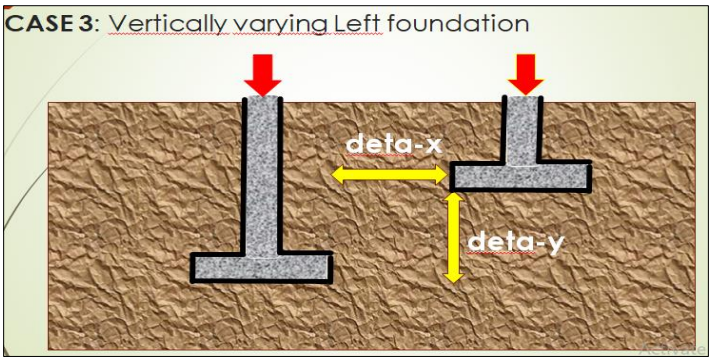


Figure 4 Vertically varying left foundation

2.4. Boundary conditions

The Figure 5 below shows the design of boundary conditions. The model has three sub-behavioral laws (Fig 6): concrete, soil and interface.

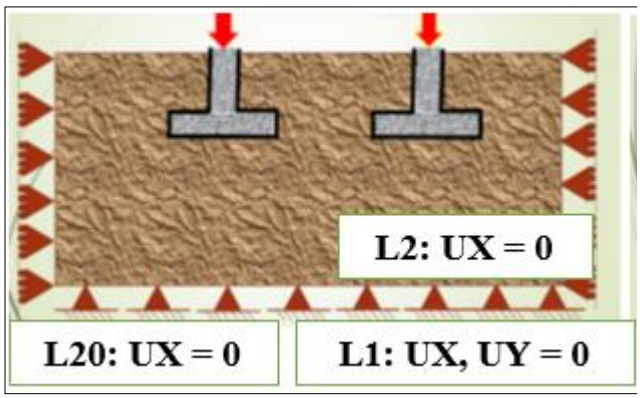


Figure 5 Boundary conditions

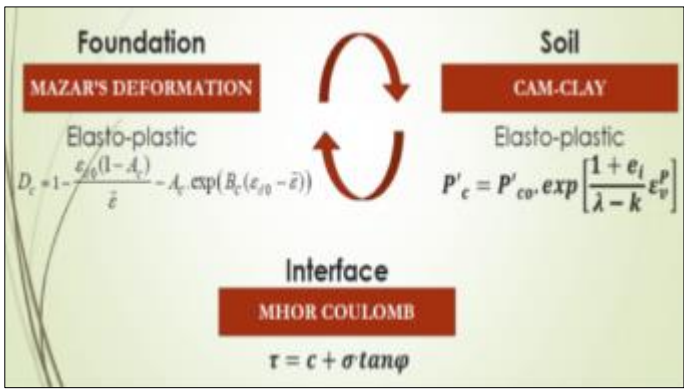


Figure 6 Three sub-behavioral laws of model

L20 = the line showing the left edge of the soil L2 = the line showing the right edge of the soil,

UX = horizontal displacement. UY = vertical displacement.

- **CL1 = BLOQ DEPLA L1;** the base of the foundation is rigid.
- **CL2 = BLOQ UX L2;** the soil on the adjacent sides do not move in the horizontal direction.
- **CL3 = BLOQ UX L20;** the soil on the adjacent sides do not move in the horizontal direction

2.5. Behavior models

2.5.1. MAZAR'S BEHAVIOR MODEL

This behavior model was formulated by [Jacky MAZARS, 1984] that permits us to describe the elastic damage behavior of concrete. It is a 3D isotropic model, formulated according to a damage criterion in deformation and describing a dissymmetry tension-compression.

The model has three sub-behavioral laws defined below

2.6. Foundation Model

2.6.1. Mazar's deformation (Elasto-plastic)

Mazar elasto-plastic model, is a constitutive model used here to describe the stress-strain behavior of soil under both elastic and plastic deformations. This model is employed to capture the complex behavior of soils, it incorporates both elastic and plastic components to represent the behavior of soil under loading. The elastic portion of the model accounts

for reversible, recoverable deformations, while the plastic portion captures irreversible deformations associated with soil yielding and failure.

It was developed by the geotechnical engineer Shlomo Mazar

$$D_e = 1 - \frac{\varepsilon_{do}(1 - A_c)}{\tilde{\varepsilon}} - A_c^{(B_c(\varepsilon_{do} - \tilde{\varepsilon}))}$$

Where: (ε_{do})= Threshold deformation in tension $(A_c) =$ Compression Parameter

$(B_c) =$ Compression Parameter D_e = elastic damage $\tilde{\varepsilon}$ = strain tensor

2.6.2. Clay Soil Model

CAM-CLAY (Elasto-plastic)

Cam-Clay model is a classic elasto-plastic constitutive model used to describe the behavior of cohesive soils. The model is a fundamental tool in geotechnical engineering for predicting the stress-strain behavior of clayey soils.

$$P'_c = P'_{co}{}^{\left[\frac{1+e_i}{\lambda-k}\varepsilon_v^p\right]}$$

2.7. Interface (Mhor Coulomb)

The interface, also known as Mohr-Coulomb failure criterion, is a fundamental concept in the field of geotechnical engineering and soil mechanics.

$$\tau = c + \sigma tan\varphi$$

Where: $\tau = shear\ stresses$ $\sigma = normal\ stress$ $\varphi = internal\ angle\ of\ \ friction$

2.8. Material

The Table 1, 2 and 3 shows the characteristics of Mazar's deformation model, the characteristics of soft clay soil of Bonaberie in Douala and the concrete-soil interface characteristics.

Table 1 Foundation (concrete) Characteristics of Mazar's deformation model [12]

Parameters	**Symbol**	**Numerical value**
Young'sModulus	E (Mpa)	27000
Volumic mass	$\boldsymbol{\rho}$ (Kg/m^3)	2500
Poisson's Ratio	$\boldsymbol{\vartheta}$	0.2
Threshold deformation in tension ($\boldsymbol{\varepsilon_{do}}$)	$\boldsymbol{KTRO}$	1×10^{-4}
Compression Parameter ($\boldsymbol{A_c}$)	$\boldsymbol{ACOM}$	1.4
Compression Parameter ($\boldsymbol{B_c}$)	$\boldsymbol{BCOM}$	1900
Tension Parameter	$\boldsymbol{ATRA}$	0.8
Tension Parameter	$\boldsymbol{BTRA}$	17000
Correction parameter for shearing	$\boldsymbol{BETA}$	1.06

Note: the symbols; KTRO, ACOM, BCOM, ATRA, BTRA, BETA

These values are inputed in the simulation process in CAST3M, found in the algorithm.

Table 2 Characteristics of soft clay soil of Bonaberi-Douala

Parameters	Symbol	Numerical value
Young's Modulus	E (Mpa)	24
Volumic mass	ρ (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)	40kPa
Pre-consolidation pressure	PO (kPa)	20kPa
Elastic slope	$KAPA$	0.02
Plastic slope	$LAMD$	0.1
Shear Modulus	$G1$(MPa)	15.4

Table 3 Concrete-Soil Interface Characteristics [13]

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

2.9. Time interval of load application

A load intensity of 50KN was applied. This loading was done following the Cast3m operator: PASAPAS, which takes into consideration time as a parameter. The Figure 7 below shows the load factor-time graph.

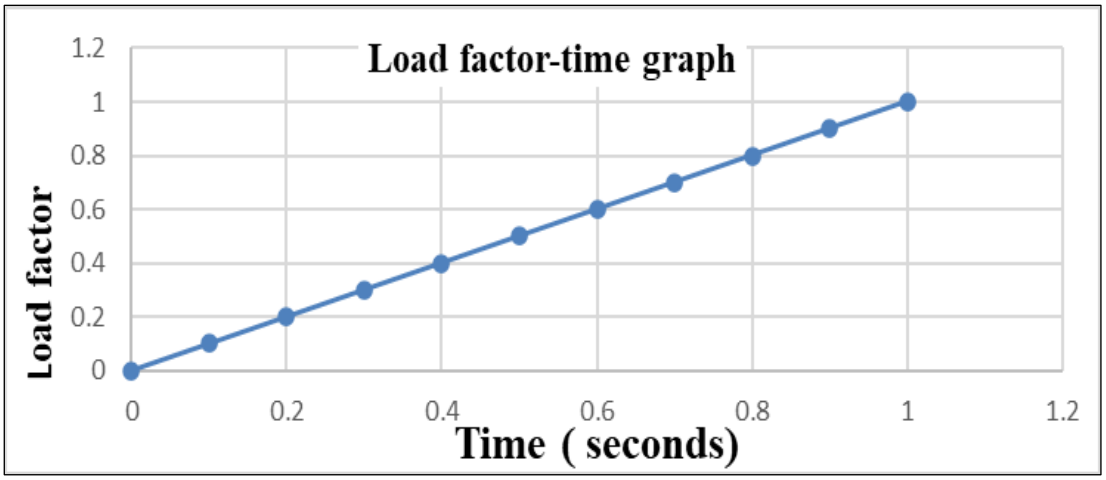


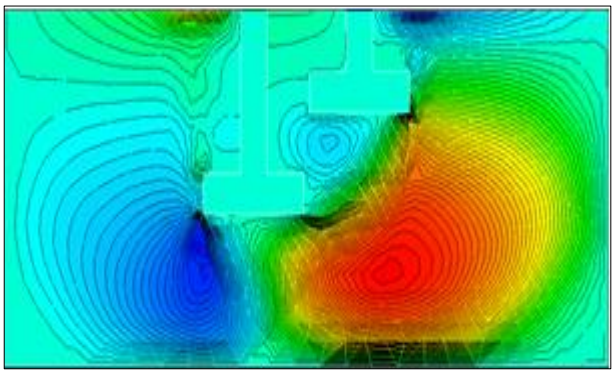
Figure 7 Load factor-time graph

The above graph represents time loading graph, with loads in KN and time in seconds, indicating that a load of 1KN is spread over a period of 1second and the results beneath were registered.

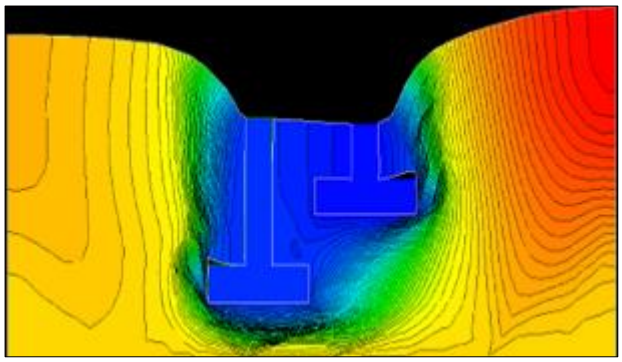
3. Results and discussion

3.1. Results

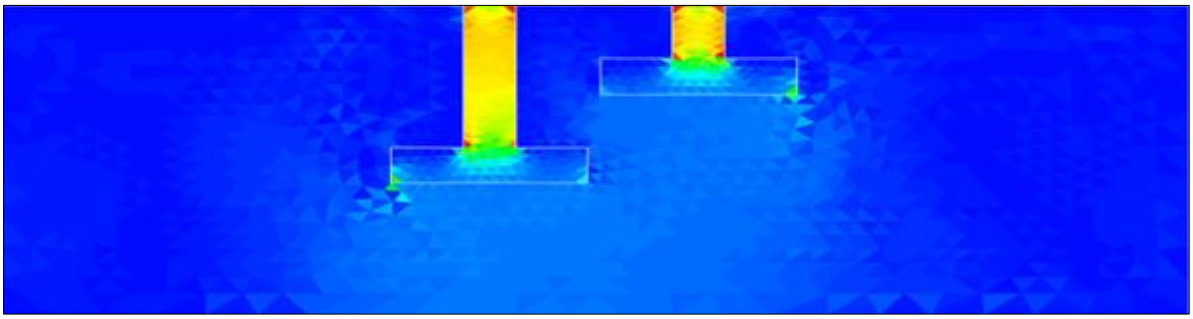
After a rigorous inputting of all the necessary data requested by the cast3m software, we had the following results. The different cases; stress-displacement graphs and stress-space separation graphs and settlement-space separation graphs. The pictures of horizontal Displacement, Vertical Displacement (Settlement) and Vertical Stress were observed (Fig. 8 and 9).



Horizontal Displacement of clay soil under load



Vertical Displacement of clay soil under load



Vertical stresses of clay soil under load

Figure 8 Behavioural out coming from the simulation

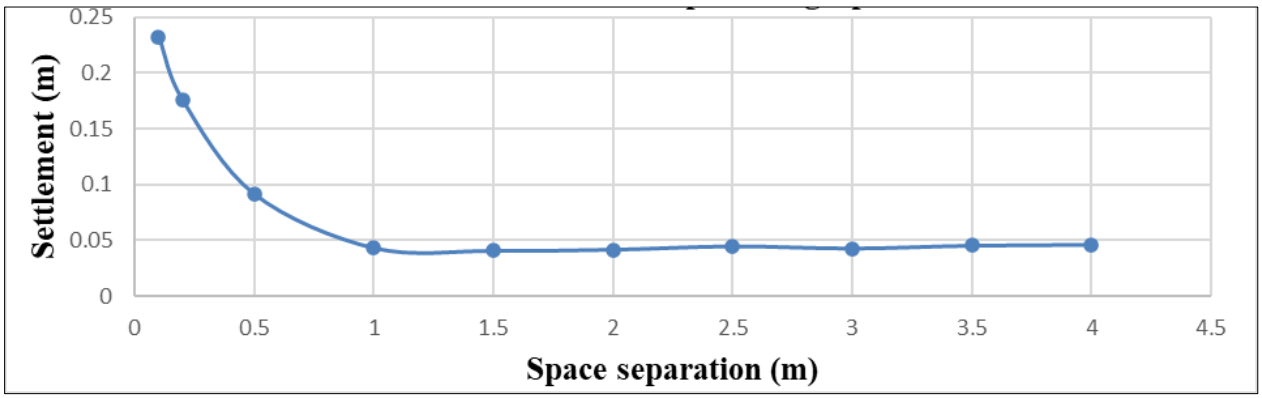


Figure 9 Settlement horizontal position graph

From the settlement-space separation graph (CASE 1), a transition zone of interactions and a permanent zone of least interactions was observed. This zone is delimited by a space separation of 1 meter. Mathematically the graph follows an exponential decay with an empirical equation as shown below.

$$y = Ae^{-\beta x} + B ----(Eq.1)$$

Where $A = \Delta h_{max} - \Delta h_{min}$, $B = \Delta h_{min}$ $\beta = reduction\ coefficient$;

Δh_{min}; minimum settlement for which there is no interaction

Δh_{max} ; maximum settlement for closes space separation

The equation can be written:

$$\frac{S}{B} \geq \frac{2}{3} \sim 0.7 \quad ----------(\text{Eq. } 2)$$

Where

S = Space separation between foundation

B = Width of foundation

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

3.2. Shear stress diagram of the soil results from the foundation

Plan of consideration is the horizontal plane; the Figure 10 show the shear stress-horizontal position.

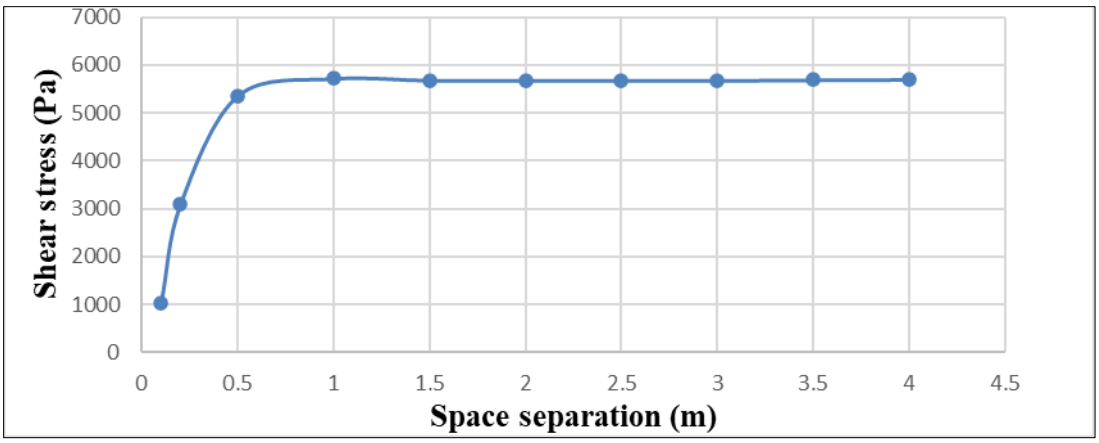


Figure 10 Shear stress-horizontal position graph

From the Maximum Shear Stress-Space Separation Graph, the Shear stress in the soil between both foundations increases and attains a limit value. This graph mathematically represents an exponential increase which can be mathematically written in the form:

$$y = \tau\left(1 - e^{\beta x}\right) ------(\text{Eq. } 3)$$

Where $shearstress\ value\ = \tau_{max}$, $\beta = reduction\ coefficient$;

The expression above gives the threshold space separation above which there is least or no Shear stress interaction between both foundations (Fig 11).

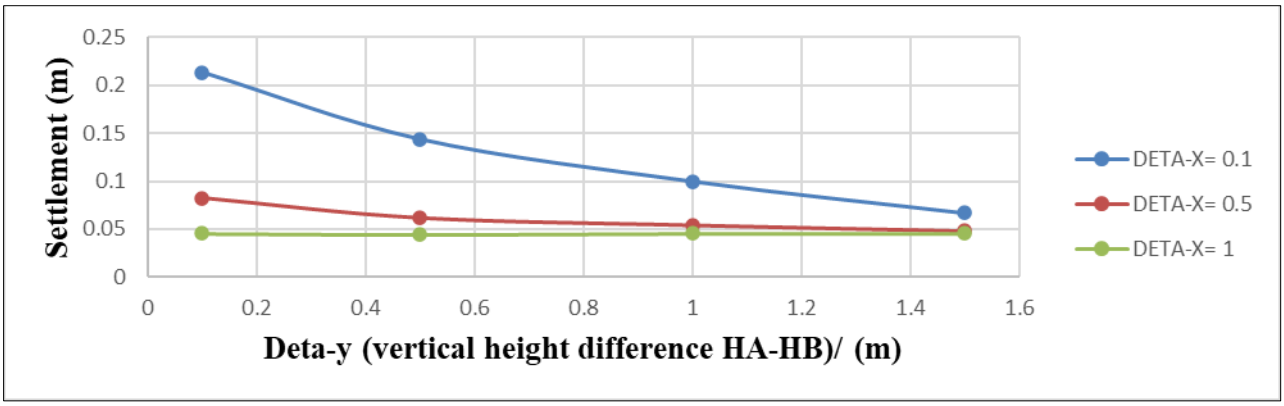


Figure 11 Settlement-vertical position graph

The combined Settlement-Vertical position graphs (CASE 2) and Stress-Vertical Position graphs clearly interprets to us the various Mid Stress-Displacement graphs:

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 1m (Fig 12).

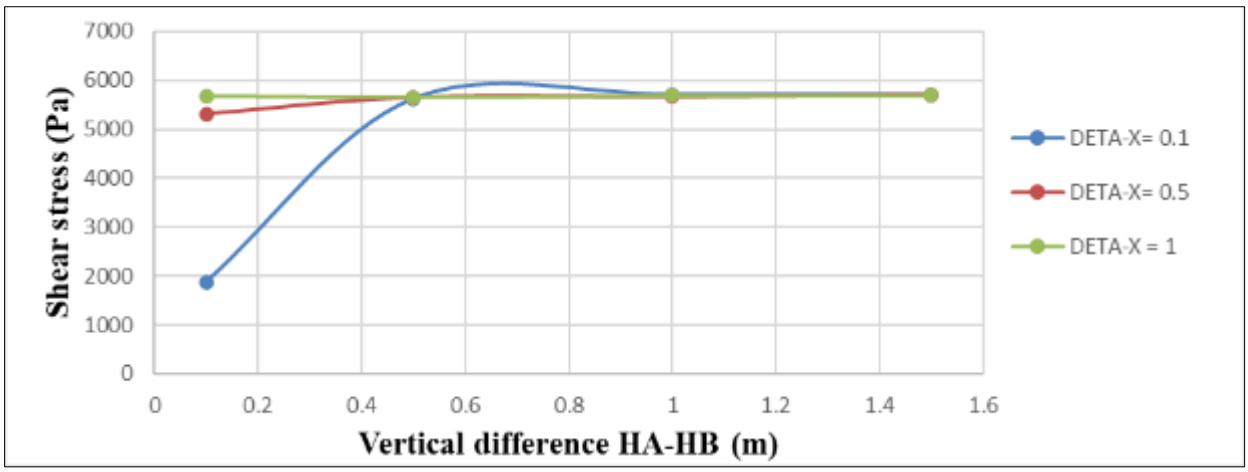


Figure 12 Shear stress-horizontal position graph

It is observed that for a very small separation, shear stress increases as the depth of the right foundation increases and becomes constants at a vertical difference of 0,5m;

The rate at which this transition occurs decreases as the space separation increases and becomes constant for a space separation (det-x) of 1,00m. (det-x = 1.00 is the thresh space separation above minimal interaction)

The Figure below (Fig 13) is a graph resulting from a combined settlement-vertical position graph for CASE 3.

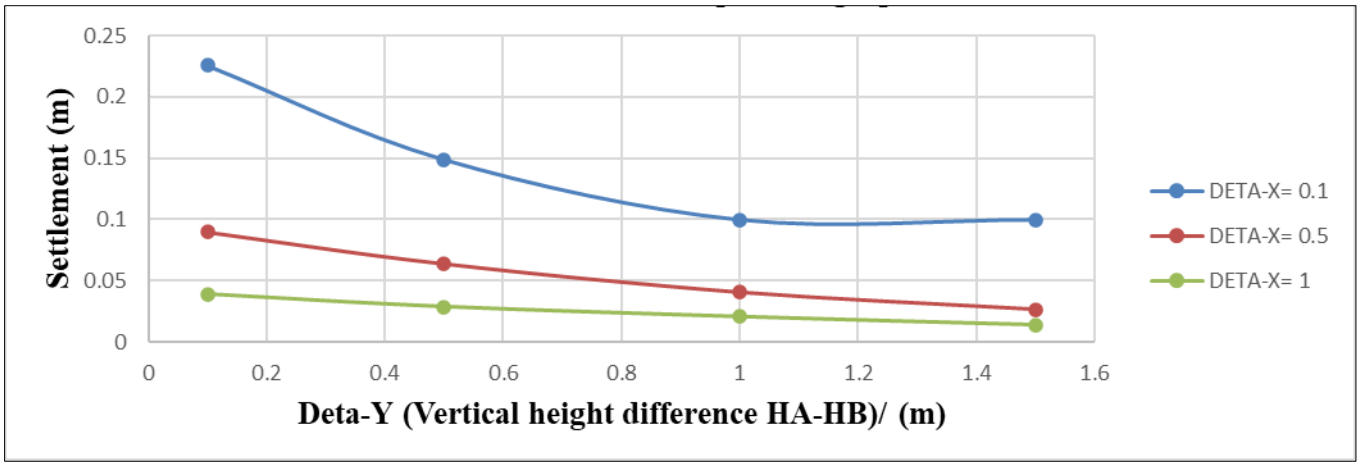


Figure 13 Settlement-vertical position graph

It is observed that the settlement of the left foundation decreases as its depth increases. This rate of settlement decrease, decreases as the space separation between the two foundations increases. Cohesion influences the settlement of the foundation. The Figure 14 below is a graph showing the influence of varied cohesion on the settlement of the foundation.

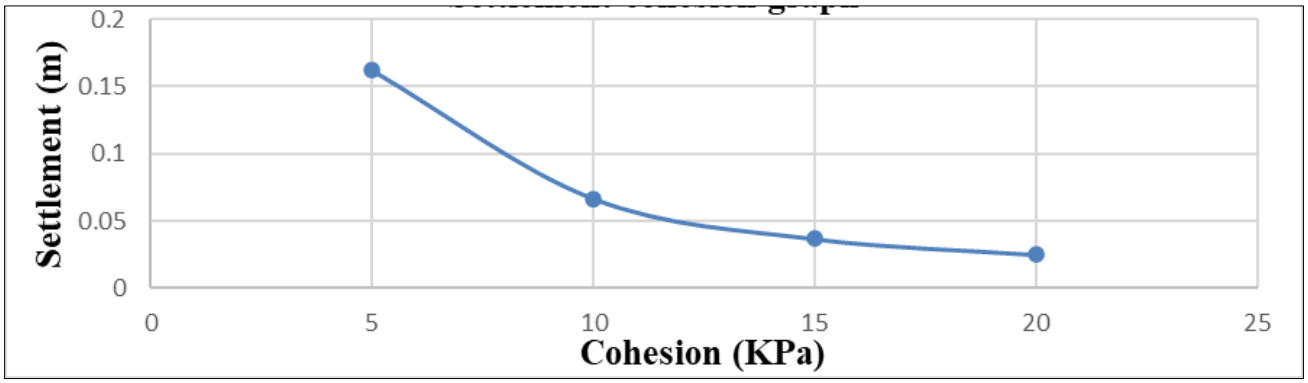


Figure 14 Settlement-cohesion graph

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. Discussion

When the foundations are at the same level, the closer the space separation, the higher the horizontal displacement of the particles at the extremities of the footing. The displacement in the soil between two foundations increases as the space separation increases. While vertically varying the right footing, the soil directly beneath the left footing to the right experiences small displacement which increases as the depth of right footing increases. Finally, when vertically varying the left footing, the displacement in the soil between the two footings increase as the depth of the left footing increases. The intensity of horizontal displacement of soil around the footings is uneven for each footing.

When the foundations are at the same level, the closer the space separation, the more the vertical displacement of the soil particles between the footings and vice-versa. When vertically varying the right footing, the depth of the right footing does not influence much the settlement on the left footing. Finally, when vertically varying the left footing, the vertical deformation under the left footing decreases as the depth of the left footing increases. This implies that the soil becomes more stable as the left footing goes deeper into the soil.

When the foundations are at the same level, the interaction of the vertical stresses (compressive stress) under each footing increases as the foundations come closer. The vertical stress under each footing has a triangular shape which corresponds to the TERZAGHI'S model of soil failure.

When vertically varying the right footing, the vertical stress under the left footing interacts in a decreasing manner with the stress under the right footing as the depth of the right footing increases. Finally, when vertically varying the left footing, the vertical stress under the left footing interacts in a decrease's manner with the stress under the right footing as the depth of the left footing increases.

5. Conclusion

The results of simulation show that closely spaced shallow foundations in a soft clay soil interact greatly as rigorously analysed and interpreted in this study. This interaction decreases as the space separation between both foundations increases-vertically and horizontally especially. For this soil case, 1m was the threshold space separation, above which there is practically no interaction between the two neighbouring shallow foundations. At the end of the simulation, the space separation versus settlement behavior follows an exponential increase whereby beyond a space separation to base ratio greater than or equal to 0.7, $(S/B \geq 0.7)$ there was no interaction. The closer the two foundations, the more the horizontal displacements at the extremities of both foundations-both foundations tend to function like a single footing when they are closely spaced. This same work can be done experimentally and compared with the numerical results; considering different soil layers, the numerical three dimensions (3D) and also considering deep foundations.

Compliance with ethical standards

Acknowledgments

The authors gratefully acknowledge the support of the mechanical laboratory of HTTTC (High Technical Teacher Training College) of University of Bamenda, the laboratory of National Higher Polytechnic Institute (NAHPI) of University of Bamenda and the mechanics laboratory of ENSET of Douala.

Disclosure of conflict of interest

No conflict-of-interest to be disclosed.

Author's contributions

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

Funding

No funds, grants or other support was received.

Declarations Conflict of interest

There is no conflict of interest about this research.

References

[1] Stuart JG (1962). Interference between foundations, with special reference to surface footings in sand. Geotechnique 12(1):15–22.

[2] West JM, Stuart JG (1965). Oblique loading resulting from interference between surface footings on sand. Proc 6th Int. Conf. Soil Mech Found Eng., Montreal 2:214–217.

[3] Selvadurai A and Rabbaa S (1983). Some experimental studies concerning the contact stress beneath interfering rigid strip foundations resting on a granular stratum. Can. Geotech. J.20, 406-415.

[4] Graham J, Raymond GP, Suppiah A (1984). Bearingcapacity of three closely spaced footings on sand. Geotechnique 34(2):173–182.

[5] Graham J, Raymond GP, Suppiah A (1984). Bearing capacity of three closely spaced footings on sand. Geotechnique 34(2):173–182.

[6] Kumar J, Ghosh P (2007). Ultimate bearing capacity of two interfering rough strip footings. Int J Geomechanics, ASCE 7(1):53–62.

[7] Ghosh P, Rajesh S and Chand JS (2017). Linear and nonlinear elastic analysis of closely spaced strip foundations using Pasternak model. Frontiers of Structural and Civil Engineering, 11(2), 228-243.

[8] Lee J and Eun J (2009). Estimation of bearing capacity for multiple footings in sand. Computers and geotechnics, 36(6), 1000-1008.

[9] Srinivasan V and Ghosh P (2011). Interaction problem of circular footings on homogeneous soil deposit. In Proceedings of Indian Geotechnical Conference (pp. 823-826).

[10] Srinivasan V and Ghosh P (2013). Experimental investigation on interaction problem of two nearby circular footings on layered cohesionless soil. Geomechanics and Geoengineering, 8(2), 97-106.

[11] Verma GA and Saran S (1990). Interference Effect on the Behavior of Footings. International Journal of Rock Mechanics and Mining Sciences and Geomechanics Abstracts, vol. 27, no. 2, 1990, pp. A110–A110.

[12] Paola F di (2011). Liste des modèles en mécanique non linéaire, édition 2011, page 29)

[13] Paola F di (2011) liste des modèles en mécanique non linéaire, édition 2011, page 23)

[14] Reddy ES, Borzooei S and Reddy GN (2012). Interference between adjacent footings on sand. International Journal of Advanced Engineering Research and Studies, 1(4), 95-8.

[15] Fichoux E.L. PRÉSENTATION ET UTILISATION DE CAST3M. ÉDITION 2011, page 11, 12.