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Settlement Analysis of Isolated Footings using PLAXIS 3D: Comparison Between Individual and Group Foundation Effects

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***Abstract*— This paper investigates the settlement behavior of isolated footings in a building structure under vertical and eccentric loading conditions using the finite element software Plaxis 3D. Two cases are considered: (1) individual footing analysis without accounting for the influence of adjacent foundations, and (2) a comprehensive model considering the interaction among all footings in the building. Geotechnical data synthesized from site investigations and footing dimensions were used as input parameters. The study compares settlement responses of corner, edge, and central footings in both cases. Results indicate that ignoring the effects of neighboring footings may lead to underestimation or overestimation of settlements. The findings highlight the importance of global modeling for reliable settlement prediction in practical design.**

***Keywords*—isolated footing; settlement behavior; eccentric loading; Plaxis 3D; finite element analysis; footing interaction; geotechnical parameters**

I. INTRODUCTION

In geotechnical engineering, foundation settlement is a critical issue because it directly affects the serviceability and safety of the structures above. In conventional design practice, isolated footings are usually analyzed individually, without considering the influence of surrounding foundations. However, in actual building conditions where multiple footings are placed close to one another, their interaction can play a significant role in the way each footing settles. Such interactions may lead to differences in settlement behavior compared to when the footings are considered separately, making it important to account for these effects in order to achieve more accurate and reliable design predictions. Plaxis 3D is an advanced tool for simulating soil–structure interaction. It can show soil and foundation behavior more realistically than simple methods. This helps engineers see the mechanism of settlement more clearly. It also allows better prediction of differential settlements and design choices. Overall, it makes settlement analysis more reliable and design safer.

This paper aims to analyze the settlement behavior of isolated footings (corner, edge, and central) under the combined effects of axial load (N), moment (M), and shear force (Q), with emphasis on the role of neighboring foundation interaction.

II. LITERATURE REVIEW

The settlement behavior of shallow foundations has been a central topic in geotechnical engineering research for decades. Classical theories, such as those of Terzaghi (1943) [1] and Poulos [2] & Davis (1974) [3], laid the groundwork for understanding settlement mechanisms and provided simplified approaches for predicting foundation performance. These pioneering studies provided the fundamental theories and empirical methods to estimate both immediate and consolidation settlements. Their approaches have been widely adopted in design practice due to their simplicity and ease of application, but they rely on a number of simplifying assumptions regarding soil behavior and foundation conditions.

With advances in computational methods, the finite element method (FEM) has become a widely adopted tool, allowing more realistic modeling of soil–structure interaction. In particular, Plaxis software has been extensively used to study the settlement and bearing capacity of shallow foundations, offering improved accuracy compared to traditional analytical approaches (Brinkgreve et al., 2016) [4].

Despite these advancements, much of the existing literature has primarily focused on the analysis of single isolated footings, often neglecting the potential influence of adjacent foundations. This simplification, while practical for conventional design, may introduce inaccuracies when applied to real structures where multiple foundations interact within a shared soil mass. Recent studies, such as those by El Sharnouby (2020) [5] and Nguyen & Pham (2022) [6], have emphasized the importance of considering group effects and continuum soil modeling in settlement prediction. Nguyen and Pham (2022) conducted a numerical study on closely spaced foundations using the finite element method. Their results showed that foundation interaction significantly increases settlement compared to isolated footing analysis, particularly when spacing is small. The study emphasized the necessity of considering group effects and soil continuum modeling for more accurate design predictions.

These works suggest that ignoring foundation interaction can result in either conservative or unconservative designs, thereby underscoring the need for more comprehensive modeling approaches in modern geotechnical practice.

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III. RESEARCH METHODOLOGY

The study was conducted using PLAXIS 3D, where the geotechnical model incorporated soil stratigraphy, material properties, and foundation geometry derived from the construction site investigation.

Geotechnical data were compiled from site investigation reports, including soil stratification and relevant physical–mechanical parameters.

The soil profile at the project site consists of three distinct strata, which can be described as follows:

The first layer is an upper sand stratum with a thickness of 2.0 m, having an unsaturated unit weight of 17.0 kN/m³ and a saturated unit weight of 20.0 kN/m³. The effective shear strength parameters are defined by a cohesion of 1.0 kN/m² and a friction angle of 31°.

The second layer consists of medium-plasticity clay with a thickness of 14.0 m. This stratum has an unsaturated unit weight of 16.0 kN/m³ and a saturated unit weight of 18.0 kN/m³, with an effective cohesion of 5.0 kN/m² and a friction angle of 25°.

The third layer is a relatively thick deposit of stiff sand, considered the most competent bearing stratum within the profile. It exhibits an unsaturated unit weight of 17.0 kN/m³ and a saturated unit weight of 20.0 kN/m³, with an effective cohesion of 1.0 kN/m² and a friction angle of 30°.

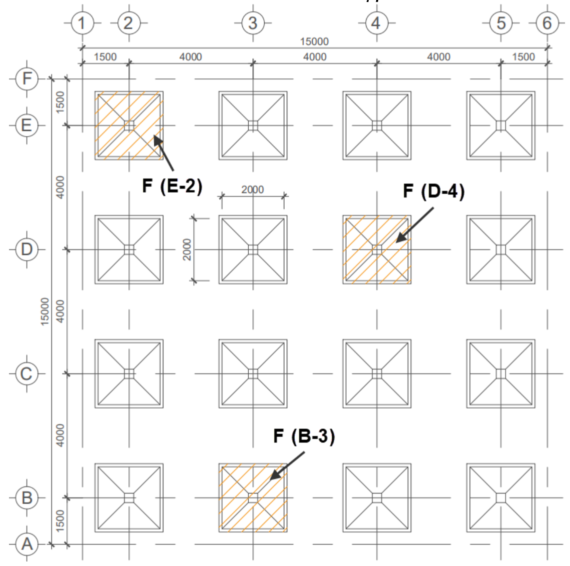

Fig. 1. Foundation layout plan.

Foundation layout was defined by the plan dimensions and loading conditions at each column base (axial force *N*, moment *M*, and shear force *Q*). The applied loads are presented in Table I. Footing dimensions: 2 m × 2 m. The embedment depth of the foundation is 1 meter.

TABLE I. APPLIED LOADS ON THE FOUNDATIONS

Load	Central footing F [D-4]	Edge footing F [B-3]	Corner footing F [E-2]
N_{max} (tonf)	60.1	57.51	58.37
M_{xmax} (tonf·m)	1.14	1.23	-1.25
M_{ymax} (tonf·m)	-1.14	1.13	1.24

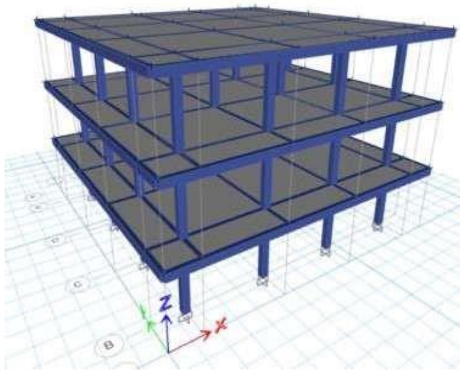

Fig. 2. Structural frame model.

Numerical modeling was performed using Plaxis 3D with the Mohr–Coulomb soil model.

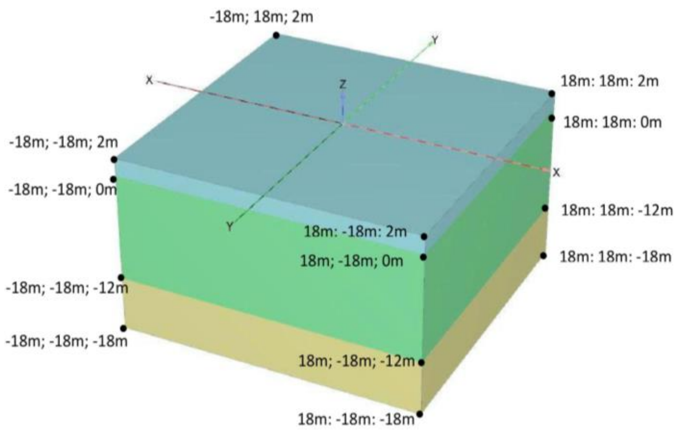

Fig. 3. Geometric modeling of soils

The input material parameters used for the Plaxis 3D simulation are presented in Table II.

TABLE II. GEOTECHNICAL AND MATERIAL INPUT PARAMETERS

Property	Upper sand	Clay	Stiff sand	Concrete	Unit
Soil model	Mohr Coulomb	Mohr Coulomb	Mohr Coulom b	Linear elastic	–
Drainage type	Drained	Drained	Drained	Non-porous	–
γ_{unsat}	17.0	16.0	17.0	27.0	kN/m³
γ_{sat}	20.0	18.0	20.0	–	kN/m³
E'_{ref}	$1.3 \cdot 10^4$	$1.0 \cdot 10^4$	$7.5 \cdot 10^4$	$3.1 \cdot 10^7$	kN/m²
Poisson's ratio	0.30	0.35	0.30	0.10	–
c'_{ref}	1.0	5.0	1.0	–	kN/m²
φ'	31	25	30	–	°
ψ	0	0	0	–	°
Strength determination	Rigid	Rigid	Rigid	Rigid	–
K_0	Auto	Auto	Auto	Auto	–

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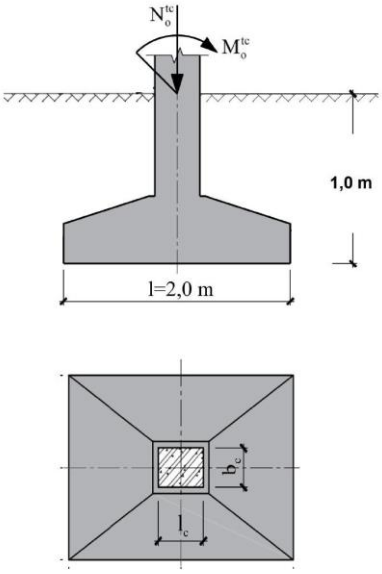

Footing dimensions: b×l = 2.0 m × 2.0 m

Fig. 4. Typical isolated shallow foundation supporting a column.

	Layer	Thickness	Description
	1	2.0 m	Sand, φ' = 31°
	2	14.0 m	Medium plasticity clay c'_{ref} = 5 kN/m² φ' = 25°
	3	6.0 m	Stiff sand φ' = 30°

Fig. 5. Soil profile.

Two scenarios were considered: (i) each footing analyzed independently without adjacent effects, and (ii) all footings modeled simultaneously to capture interaction.

The analysis procedure involved evaluating settlement contours, vertical displacements, and stress distributions beneath corner, edge, and interior footings, followed by comparative assessment.

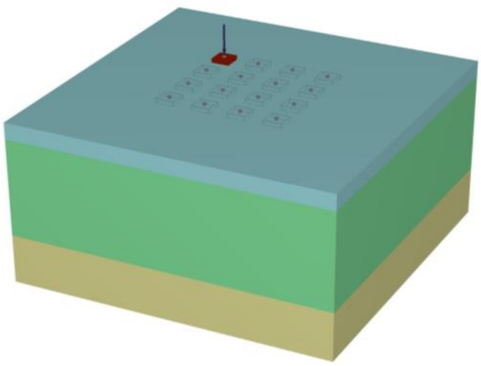

Fig. 6. Numerical simulation of the corner footing [F(E-2)] of the structure using PLAXIS 3D

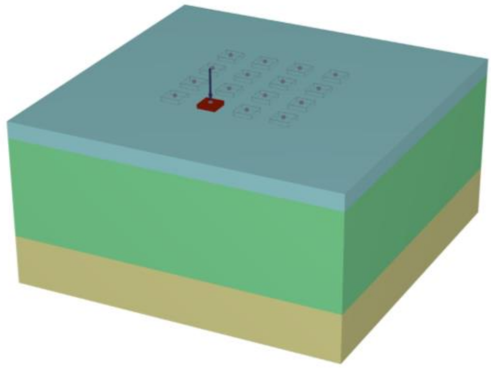

Fig. 7. Numerical simulation of the edge footing [F(B-3)] of the structure using PLAXIS 3D.

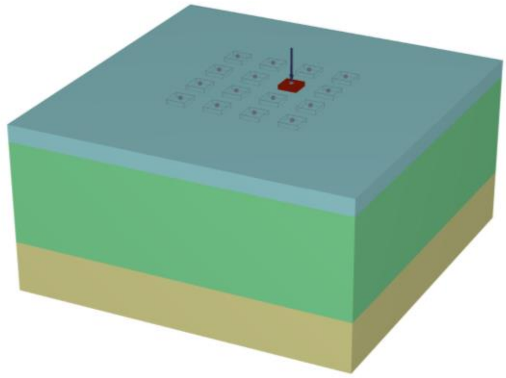

Fig. 8. Numerical simulation of the central footing [F(D-4)] of the structure using PLAXIS 3D.

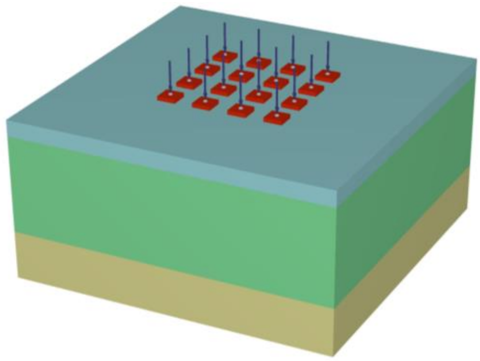

Fig. 9. Numerical modeling of all footings of the structure in PLAXIS 3D.

Cases Studied:
Case 1: Each footing modeled independently without considering adjacent footings.
Case 2: All footings modeled simultaneously to capture interaction effects.

IV. RESULTS

The consolidated results of the settlements of the footings located at the corner, edge, and central positions of the structure, under two scenarios—considering and disregarding the influence of neighboring footings—in the Plaxis 3D numerical simulation are illustrated in Table 4 and Figures 6 to 9. These results provide a comparative overview of the footing behavior in different locations within the structure and highlight the effect of adjacent footing interaction on the predicted settlement responses.

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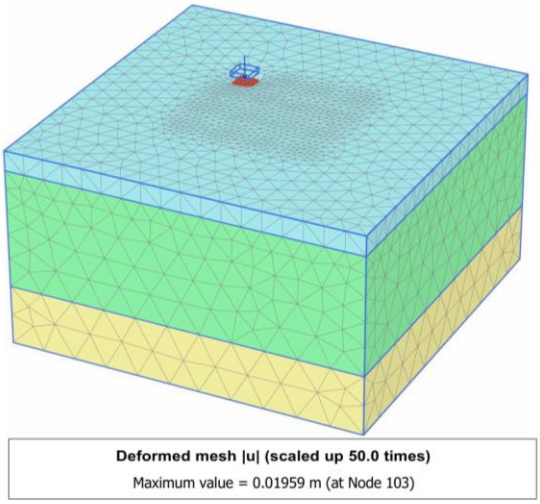

Fig. 10. Displacement results of footing F (E-2) from Plaxis 3D simulation (Case 1).

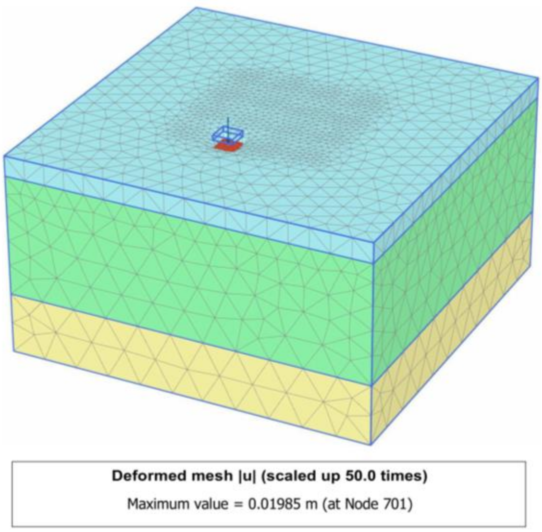

Fig. 11. Displacement results of footing F (B-3) from Plaxis 3D simulation (Case 1).

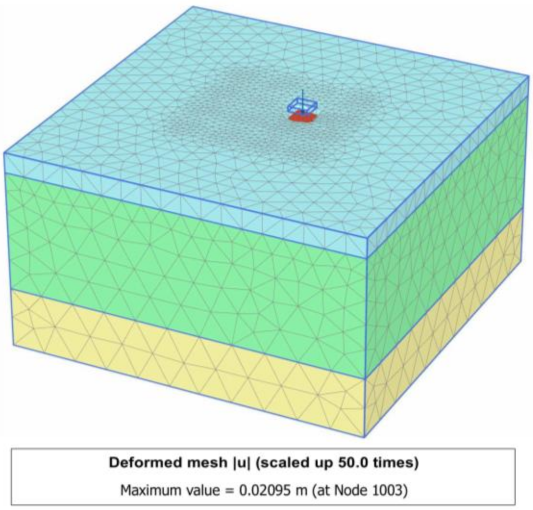

Fig. 12. Displacement results of footing F (D-4) from Plaxis 3D simulation (Case 1).

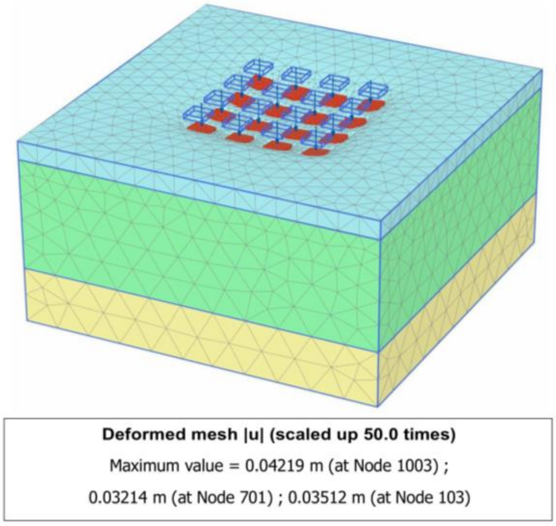

Fig. 13. Displacement results of the footings in the structure from Plaxis 3D simulation (Case 2).

4.1. Case 1: Independent footing analysis

The settlements of corner, edge, and central footings were obtained from Plaxis 3D simulations without considering the influence of adjacent foundations. The maximum vertical displacements are summarized in Table III.

TABLE III. SETTLEMENT RESULTS FOR CASE 1 (ISOLATED FOOTING ANALYSIS)

Footing position	Maximum settlement (cm)	Node reference
Corner footing, F (E-2)	1.959	Node 103
Edge footing, F (B-3)	1.985	Node 701
Central footing, F (D-4)	2.095	Node 1003

Figures (10–12) illustrate the deformed mesh and settlement contours for each footing type. The results indicate that the settlements are relatively uniform, with corner footing settlement slightly higher than the edge and central footing.

4.2. Case 2:Global foundation analysis

In the second scenario, the entire building foundation system was modeled simultaneously to capture the interaction among footings. Settlement contours show that stress fields overlap, leading to higher soil deformation beneath the group of footings. Figures 13 illustrate the deformed mesh and settlement contours for this case. The settlement results as well as the increase in settlement compared to Case 1 are presented in Table IV.

TABLE IV. SETTLEMENT RESULTS FOR CASE 2 (GLOBAL FOOTING INTERACTION)

Footing position	Maximum settlement (cm)	Difference compared to Case 1 (cm)	Rate of increase (%)
Corner footing F (E-2)	3.512	$\Delta s_{corner} = 1.50$	79.3
Edge footing F (B-3)	3.214	$\Delta s_{edge} = 1.23$	61.9
Central footing F (D-4)	4.219	$\Delta s_{central} = 2.12$	101.4

4.3. Comparison of Case 1 and Case 2

The settlements in Case 2 are generally higher than in Case 1, especially for central footings, due to the overlapping stress zones and group effects.

The differential settlement between corner, edge, and central footings increases when foundation interaction is considered.

Ignoring group effects (Case 1) may underestimate total settlements, particularly for interior footings.

Figure 14 presents a comparative chart showing the difference in settlements between Case 1 and Case 2 for the three footing positions.

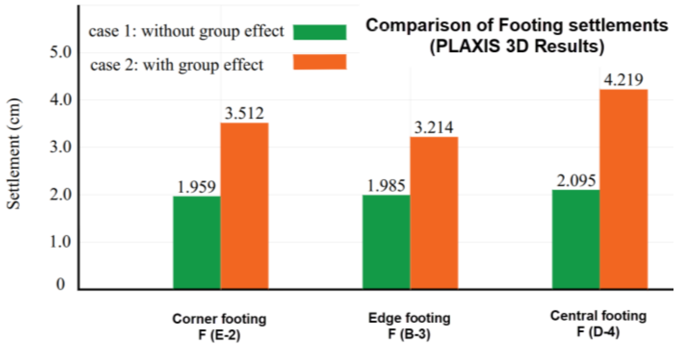

Fig. 14. Comparison chart of foundation settlements from PLAXIS 3D simulations between Case 1 and Case 2.

Observation: From the chart, it is evident that the settlement increases significantly when the group effect of footings is taken into account. The greatest difference is observed at the central footing, while the corner footing is less affected compared to the edge and central footings.

V. DISCUSSION

The numerical results clearly indicate that the interaction between adjacent footings has a significant influence on the settlement behavior of shallow foundations. In Case 1, where the effect of neighboring footings was ignored, the predicted settlements of corner, edge, and central footings were consistently lower. However, in Case 2, when the entire group of footings was modeled simultaneously, the settlements increased noticeably for all footing positions.

This difference highlights the importance of considering the group effect in geotechnical analysis. The load transfer and stress distribution in soil layers beneath the structure are not confined to a single isolated footing but are shared among adjacent foundations. As a result, the compressibility of the soil mass is mobilized more extensively, leading to larger settlements when multiple footings act together.

The comparison also reveals that the central footing experienced the highest settlement increment between the two cases. This can be explained by the overlapping stress zones generated by surrounding footings, which amplify the deformation in the central soil mass. In contrast, the corner footing is influenced by fewer neighboring foundations, and thus its settlement increase is relatively smaller. The edge footing demonstrates intermediate behavior, as it is affected by adjacent footings on only two sides.

These findings are consistent with previous studies on the group effect of shallow foundations and confirm that neglecting the interaction among footings may result in an underestimation of settlements, potentially compromising the serviceability assessment of the structure. Therefore, in practical design, numerical modeling with consideration of the entire foundation system should be preferred to achieve a more reliable prediction of ground deformation.

VI. CONCLUSION

This study presented a numerical investigation of the settlement behavior of shallow footings using Plaxis 3D under two scenarios: (i) analysis of isolated footings without considering neighboring foundations, and (ii) analysis of the entire footing system to capture group interaction effects. The results demonstrate that:

Settlements obtained from isolated footing analysis (Case 1) are consistently smaller than those from the global analysis (Case 2).

The central footing shows the largest increase in settlement when group effects are included, due to the cumulative influence of surrounding foundations.

Corner footings are least affected, while edge footings exhibit intermediate behavior between corner and central positions.

Neglecting footing interaction may lead to an underestimation of settlement, particularly in the central zones of the foundation system, which could compromise serviceability design.

Overall, the findings confirm the necessity of considering the group effect in settlement analysis of shallow foundations. Numerical modeling of the entire foundation system provides a more realistic prediction of soil deformation and should be adopted in engineering practice for reliable geotechnical design.

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