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Parametric Study of Settlement in Shallow Foundations of Adjacent Buildings on Sandy Soil: A Finite Element Parametric Study

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A B S T R A C T

Urban densification and limited availability of suitable land often necessitate the construction of high-rise buildings in close proximity. Such developments can lead to seismic-induced settlements not only beneath the new structures but also in neighboring existing buildings. This study employs a finite element approach using PLAXIS to evaluate the settlement interaction of adjacent shallow foundations on sandy soils under seismic loading. A parametric investigation was conducted to assess the effects of building height (number of stories), foundation width, and spacing between adjacent buildings. Results indicate that the spacing between buildings is the most influential parameter in controlling induced settlement in existing structures, followed by the number of stories of the newly constructed building. In contrast, foundation width showed only a marginal impact on induced settlement. The findings emphasize the importance of soil–structure interaction in urban environments and provide practical insights for mitigating seismic risks and ensuring the safety of adjacent structures.

1. Introduction

In most cases, the loads transferred through shallow foundations vary significantly, leading to differential settlements that can cause considerable damage to the superstructure. Settlement of foundations under surcharge-induced stresses has long been a major concern in geotechnical engineering. When the magnitude of total or, more critically, differential settlement exceeds the allowable limits prescribed by design codes, structural and nonstructural damages may occur, including cracks in walls, distortion of doors and windows, and failures in utility systems such as water and sewage pipelines. The problem becomes more pronounced when two buildings are constructed adjacent to each other on similar subsoil conditions. In such cases, additional stress concentrations may develop beneath the existing foundation, resulting in increased total and differential settlements that can compromise structural integrity. From a geotechnical perspective, the construction of a new building beside an existing one introduces two primary risks: (a) soil failure or lateral movement adjacent to the existing foundation due to excavation for the new footing, which may cause wall collapse or lateral displacement of the excavation face; and (b) non-uniform settlement of the existing foundation arising from the stress increase imposed by the new structure. In the latter case, the side of the existing building closest to the new construction experiences larger vertical stress increments, leading to higher settlement and potential tilting of the entire structure.

In many urban areas, regulatory authorities have established comprehensive guidelines to control excavation activities and to mitigate potential damage to existing buildings located adjacent to construction sites. However, no specific regulations are typically enforced regarding the control of differential settlements in existing structures caused by stress increments from newly constructed buildings. As a result, numerous old buildings have experienced non-uniform settlements due to adjacent construction, leading to cracks in walls, distortions in ceilings, and in severe cases, structural deterioration.

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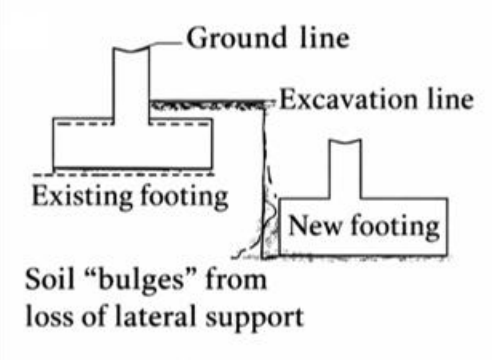

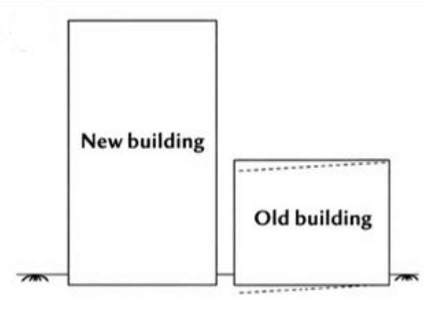

(a) **(b)**

Fig. 1. Effect of new foundation construction on the performance of an existing footing: (a) soil failure and lateral displacement due to excavation; (b) non-uniform settlement of the existing foundation induced by adjacent building construction.

Fig. 2 illustrates an example of structural damage in an old building caused by differential settlement induced by adjacent foundation loading.

Fig. 2. Example of wall cracking and structural damage in an existing building caused by differential settlement due to adjacent construction.

The interaction between adjacent foundations has been the subject of extensive research. Das and Larbi-Cherif [1] showed through physical model tests on sand that settlements increase significantly when center-to-center spacing is less than 4.5 times the foundation width. Similarly, Amer and Romi [2] demonstrated that for clay soils, settlement and tilting of flexible strip footings increase as spacing decreases, with tilting directed toward the system center and influenced by both applied load and spacing.

Numerical studies by Jao et al. [3] for reinforced concrete strip footings on cohesive soil provided equations linking settlement interference to relative spacing. Physical modeling studies by Kumar and Saran [4] highlighted the mitigating effect of geogrid reinforcement on tilting, while Kumar and Bhoi [5] reported that settlement at ultimate load increases with decreasing spacing and higher soil friction angles. Ghosh and Sharma [6] further demonstrated that settlement of interacting footings on layered soils can be reduced by improving the weaker layer. Kusakabe et al. [7] demonstrated that the growing availability of spatial data and advances in computational science have enabled large-scale three-dimensional analyses of soil–structure interaction for evaluating soil liquefaction. However, the highly nonlinear and multi-physical nature of such models leads to significant computational challenges. In this regard, they proposed an efficient finite element approach that integrates several high-performance computing techniques to conduct large-scale 3D liquefaction simulations, demonstrating its effectiveness in analyzing grid-form ground improvement systems.

Hwang et al. [8] investigated the effects of seismic structure–soil–structure interaction (SSSI) between adjacent shallow-founded buildings on liquefiable soils through dynamic centrifuge tests and 3D numerical simulations. Their results highlighted that foundation spacing, relative building height and mass, and the geometry of the neighboring structures significantly influence system performance. SSSI was found to slightly reduce settlement but increase tilt, especially when the spacing between buildings was smaller than their width. The study emphasized that SSSI can notably affect key seismic demand parameters even at relatively large separations, underscoring the need to consider these interactions in the seismic design and liquefaction assessment of urban structures.

Tian et al. [9] examined the city-scale effects of tall buildings on the seismic responses of nearby shorter structures in the Shanghai Central Business District using nonlinear time-history analyses. Their results showed that due to the large mass and long fundamental periods of tall buildings, seismic perturbations can influence a wide surrounding area, altering ground motion energy and increasing the seismic demands and potential damage of adjacent shorter buildings. The study emphasized the necessity of accounting for these large-scale interactions when assessing the seismic safety of densely built urban areas.

Hwang et al. [10] investigated the effectiveness of stiff in-ground structural walls as a countermeasure against liquefaction-induced deformations using 3D fully coupled nonlinear finite-element analyses validated by centrifuge tests. The study revealed that while structural walls can reduce foundation settlement in many cases, they may also increase residual tilt or amplify settlement under certain soil conditions, such as thick dense crust or uniform dense sand layers. The wall penetration depth and flexural stiffness were key factors influencing mitigation performance, with the crust thickness being the most critical parameter overall. The results emphasized that the design of such walls must carefully consider the coupled soil–foundation–structure interaction and site-specific ground motion characteristics.

Kassas et al. [11] examined the effects of structure–soil–structure interaction (SSSI) on adjacent shallow-founded buildings over liquefiable sand using fully coupled hydromechanical analyses with the PM4Sand model. Their results, validated against centrifuge experiments, showed that while SSSI can reduce settlement, it significantly increases foundation rotation, especially when the spacing between buildings is small. The severity of this effect depends on the liquefiable layer depth and the gap between structures. The study highlighted that SSSI can have both beneficial and detrimental impacts on seismic performance, underscoring the need to consider these interactions in the seismic design of closely spaced buildings on liquefiable soils.

Barrios et al. [12] conducted geotechnical centrifuge experiments at JNIOSH in Tokyo to investigate the seismic behavior of stand-alone and closely spaced shallow foundations on saturated sand. Using harmonic excitations in a laminar box, the study compared foundation–soil responses with free-field conditions. Results showed that adjacent footings exhibited inward tilting and reduced soil dilation beneath the foundations compared to isolated ones. Settlement was primarily caused by footing penetration into the supporting sand, and acceleration attenuation in the near-surface soil was smaller in the presence of foundations. The findings highlighted the significant influence of foundation proximity on the dynamic soil–foundation–structure interaction.

Hwang et al. [13] investigated the effects of ground densification on the seismic performance of isolated and adjacent buildings on liquefiable soils using 3D fully coupled nonlinear finite-element analyses validated by centrifuge tests. The study showed that while ground densification effectively reduces settlement when extending through the full depth of the critical layer, it may also increase foundation tilt and structural deformation, especially in asymmetric or closely spaced configurations. The influence of densification on structure–soil–structure interaction (SSSI) was found to depend strongly on treatment geometry, building spacing, and structural properties. These findings highlight the need for careful design of densification geometry and placement in urban environments with neighboring buildings.

Bagheri et al. [14] evaluated the seismic performance of two adjacent 30-story high-rise buildings, one with a conventional moment-resisting frame (MF) and the other with a dual system incorporating shear walls (MFSW), considering soil–structure interaction (SSI) using a hybrid piled raft foundation. Nonlinear dynamic analyses under multiple ground motions showed that the MFSW system significantly reduced fundamental periods, interstory drifts, and soil shear strains, enhancing overall resilience. The study also highlighted critical effects of seismic-induced soil–pile–structure interaction (SSPSI) on displacement amplification and emphasized that optimized hybrid pile configurations improve foundation performance. These findings underscore the importance of integrating superstructure design and foundation–soil interaction in the seismic assessment of high-rise buildings.

Accordingly, the present study aims to address these gaps by integrating numerical modeling [14-23] and experimental investigations [24, 25], as presented herein.

Despite these insights, a systematic investigation of factors affecting settlement due to the construction of a new structure adjacent to an existing one remains limited. The present study addresses this gap using PLAXIS, a finite element-based software, to examine the influence of the number of stories, spacing between foundations, and foundation width on settlement behavior.

2. Validation

As noted in previous sections, PLAXIS (version 8.5), a two-dimensional finite element software capable of simulating and solving geotechnical problems, was employed in this study to evaluate the effects of adjacent buildings on the settlement of existing structures. Since numerical results are highly dependent on the quality of input parameters, the outputs generated by such software may deviate significantly from reality. Therefore, prior to application, the software must be validated or calibrated to ensure the reliability of its predictions. Various calibration methods are reported in the literature, with the most reliable approach being the use of field-measured data from instrumented geotechnical projects.

In this study, geotechnical monitoring data from the Esfandiar Tunnel in northern Tehran were used for validation. This tunnel, excavated within soil deposits, provides comprehensive instrumentation data, including surface settlement measurements recorded during construction, which were utilized in this research. The ultimate goal of software validation is to confirm both the proper functioning of the numerical model and the accuracy of its outputs. In cases where the discrepancy between the validation model and the actual measurements is less than 15%, the software is considered reliable. The section of the tunnel under study is approximately 520 m long, featuring two traffic lanes and a maximum height of 6.5 m. The geological and geotechnical profile of the tunnel alignment, shown in Fig. 3, includes a range of soil types from coarse sandy alluvium to finer clay layers. Accurate modeling of any civil engineering project requires precise knowledge of the geotechnical properties of the constituent soils. Extensive investigations, including exploratory boreholes, laboratory tests, and in-situ tests, were conducted for the Esfandiar Tunnel to characterize the soil layers. Table 1 summarizes the basic properties and main geotechnical parameters of the different soil strata, which were used as input data for software validation.

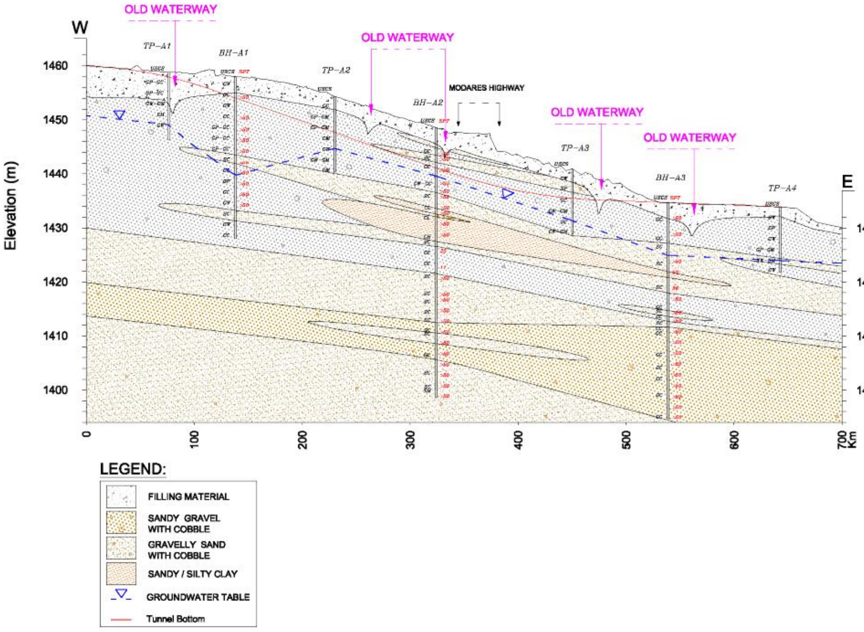

Fig. 3. Geological and geotechnical profile of the studied tunnel section.

Table 1. Summary of the main geotechnical soil parameters for the studied section.

Geotechnical parameters of the sand layer (GC, GM)	
Internal friction angle	$\varphi = 34 \sim 38$
Cohesion	$X = 0.15 \sim 0.3\ \mathrm{kg/cm^2}$
Wet density	$\gamma = 1.90\ \mathrm{g/cm^3}$
Poisson’s ratio	$\nu = 0.30$
Deformation modules	$E = 600 \sim 900\ \mathrm{kg/cm^2}$
Permeability	$K = 5E-5 \sim 5E-4\ \mathrm{cm/s}$
Geotechnical parameters of the sand layer (SC, SM)	
Internal friction angle	$\varphi = 32 \sim 34$
Cohesion	$C = 0.2 \sim 0.4\ \mathrm{kg/cm^2}$
Wet density	$\gamma = 1.85\ \mathrm{g/cm^3}$
Poisson’s ratio	$\nu = 0.32$
Deformation modules	$E = 500 \sim 700\ \mathrm{kg/cm^2}$
Permeability	$K = 1E-5 \sim 1E-4\ \mathrm{cm/s}$
Geotechnical parameters of the fine-grained layer (CL)	
Internal friction angle	$\varphi = 22 \sim 24$
Cohesion	$C = 0.3 \sim 0.5\ \mathrm{kg/cm^2}$
Wet density	$\gamma = 1.98\ \mathrm{g/cm^3}$
Poisson’s ratio	$\nu = 0.4$
Deformation modules	$E = 300 \sim 500\ \mathrm{kg/cm^2}$
Permeability	$K = 1E-6 \sim 1E-8\ \mathrm{cm/s}$

In the Esfandiar Tunnel project, surface settlements were precisely recorded over different time intervals along the studied section. An illustration of these measurements is presented in Fig. 4. As indicated by the monitoring data, the surface settlement ranged between 30 and 60 mm within the study area. Subsequently, the tunnel section was numerically simulated using PLAXIS, and the surface settlements predicted by the software were compared with the field-measured values. The results of this comparison are presented in Fig. 5.

Since multiple sections with recorded surface settlements exist along the studied tunnel, only three representative sections were selected for comparison with the numerical results to avoid data complexity. The surface settlement results for these three sections, along with the predictions from PLAXIS, are presented in Fig. 5. The first observation from these graphs is that the surface settlement patterns predicted by the software closely match the field-measured settlement profiles, which represent the actual ground behavior.

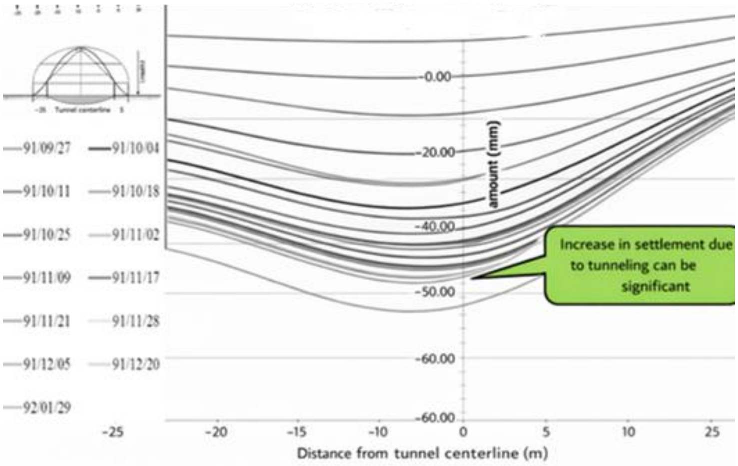

Fig. 4. Surface settlements recorded at different time intervals along the validated section.

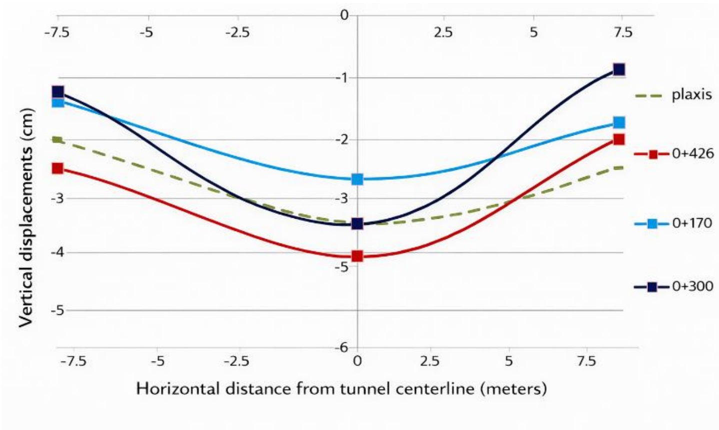

Fig. 5. Comparison of surface settlements between the studied section and the developed numerical model.

In other words, the shape of the ground settlement observed in reality is well reproduced by the numerical model, showing a characteristic bell-shaped profile in both cases. Furthermore, the maximum settlements predicted by the software are very close to the measurements recorded at different sections. The minor discrepancies can be attributed to geological variations and the inherent uncertainty in determining precise geotechnical parameters of the different soil layers. Therefore, this comparison confirms the reliability and accuracy of the software, allowing confident use of its outputs for subsequent analyses.

3. Numerical modeling of the problem

The assessment of the effects and performance of new structures on pre-existing buildings has long been recognized in civil engineering literature as a complex and ambiguous issue. The construction of a new structure adjacent to existing buildings can induce various effects, with settlement being the most critical factor, as it can significantly influence the deformations and settlements imposed on the pre-existing structures. Accordingly, this study investigates the various aspects of constructing a new building and its effects on the induced deformations and settlements of existing structures.

For numerical and parametric analyses of the influence of new structures on existing ones, it is first necessary to define the problem and represent it within a numerical environment. Moreover, to enable comparison of outputs across different models, the modeling conditions must be consistent. In this study, all numerical models are formulated based on plane strain assumptions. Fifteen-node triangular elements were used for the soil domain, while five-node elements were employed for structural components such as building foundations.

Although this study is parametric in nature and does not require actual field data, the most precise soil parameters available within the software were used for the soil elements. Another important aspect of numerical model development is the constitutive model of the soil. In this study, the soil behavior is represented using the Elastic–Perfectly Plastic Mohr–Coulomb model, which has been widely applied in both scientific research and practical projects. Further details regarding the constitutive model used will be provided in subsequent sections.

The Mohr–Coulomb (MC) model was adopted based on the objectives and strain levels relevant to this study. The applied seismic loading is represented through quasi-static equivalent lateral forces rather than full dynamic time histories; therefore, the analysis does not aim to simulate cyclic pore-pressure generation, stiffness degradation, or liquefaction mechanisms for which advanced cyclic constitutive models (e.g., PM4Sand, UBCSAND) are required.

The soil profile consists of non-liquefiable, medium-dense sand subjected to low-to-moderate shear strain levels. Under such conditions, the MC model has been shown to provide sufficiently accurate predictions of global deformation and settlement behavior. Since the focus of the research is on evaluating seismic-induced settlement interaction, not on reproducing cyclic stress–strain loops or hysteretic soil response, the use of a more sophisticated model was not essential for the intended performance metrics.

Boundary conditions for all numerical models were defined such that lateral displacements along the left and right boundaries (X-direction) were restricted, while vertical displacements (Y-direction) were allowed. The bottom boundary was fixed in both X and Y directions.

Rayleigh damping with small-strain damping ratios of 2–5% was adopted to represent material damping under quasi-static loading conditions. Standard visco-elastic absorbing boundaries provided by PLAXIS 2D were applied along the model sides to minimize artificial reflections and boundary effects. These modeling details are included here to ensure transparency of the numerical setup.

4. Parametric studies

As is well known, a parametric study involves the evaluation of influencing factors on a given subject individually. In this study, various factors arising from the construction of a new structure adjacent to an existing building were investigated. The effects of each factor on the displacements and settlements of the pre-existing structure were examined, and the parameters considered are listed as follows:

- Number of stories of the new structure
- Width of the new foundation
- Horizontal distance between the new and existing structures

For each modeling scenario, the numerical model must have well-defined boundary conditions to control nodal displacements and rotations during analysis, ensuring accurate stress distribution and displacement patterns. PLAXIS provides robust tools to define such boundary conditions. In most geotechnical numerical models involving foundations and subgrades, it is essential to geometrically define the foundation layer so that stresses and displacements in various directions can be accurately calculated. Accordingly, the boundaries around the foundation layer must be defined, and horizontal and vertical displacements along the edges must be specified.

It is important to ensure that the model boundaries are sufficiently far from the load application area so that boundary effects do not influence the studied structure. PLAXIS includes a standard fixity tool that allows straightforward generation of appropriate boundary conditions for most numerical modeling problems. In all models developed in this study, the weight of each story was considered as one ton per square meter, equivalent to approximately 10 kN, in accordance with commonly used codes such as ABA and ASTM. To monitor settlement in the numerical model, three points were selected for comparison: one at the center of the new structure, one at the center of the existing structure, and one at the edge of the foundation nearest to the new building, as shown in Fig. 6. For consistency in comparing different models, all output data were recorded at these three points.

In this study, shear modulus variation due to strain-dependent soil softening was not considered because the analysis does not involve seismic or cyclic loading conditions. The numerical framework is limited to quasi-static settlement behavior of adjacent shallow foundations, where small-strain stiffness assumptions are generally adequate. Accordingly, the Mohr–Coulomb constitutive model in PLAXIS, which employs a constant small-strain shear modulus, was adopted. This limitation has now been explicitly acknowledged to ensure that readers do not interpret the analysis as representing dynamic or strain-dependent degradation mechanisms.

Although the use of a 2D plane-strain model provides a reasonable approximation for long-building configurations where strip footings extend considerably in the out-of-plane direction, it inherently neglects three-dimensional effects. In real conditions, 3D load distribution, edge effects, and spatial stress paths may either amplify or reduce settlement interaction between adjacent foundations. Therefore, the results presented in this study should be interpreted as representative of idealized long-strip footing behavior, and future research employing full 3D numerical modeling is recommended to more comprehensively capture these spatial effects.

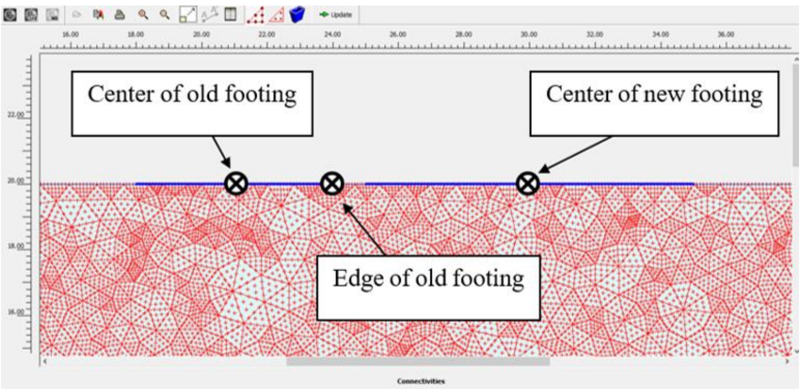

Fig. 6. Selected points for plotting settlement diagrams.

4.1. Effect of the number of stories of the new structure

One of the primary factors influencing surface displacements and deformations is the load imposed by the number of stories of a building. To examine the effect of the number of stories on the settlement of adjacent structures, buildings with varying numbers of stories, 2, 4, 6, and 8, were considered in this study. The selection of these story numbers is based on the fact that such buildings are more prevalent in the study area.

For simulating the building loads, the distributed load option in PLAXIS was used, with two separate loading systems, A and B, defined for the existing and the new structures. Each loading system in PLAXIS can be activated or deactivated at different stages of the simulation as required. It should be noted that in each parametric study, only the factor under investigation is varied while all other model properties remain constant. Accordingly, to evaluate the effect of the number of stories of the new building on the settlement of the existing structure, the horizontal distance between the two buildings was fixed at 1 m, the foundation width of the new building was set to 10 m, and that of the existing building to 6 m. The subsoil was assumed to be sandy. The results of the analysis regarding the influence of the number of stories on the settlement of the existing structure are presented in the following figures.

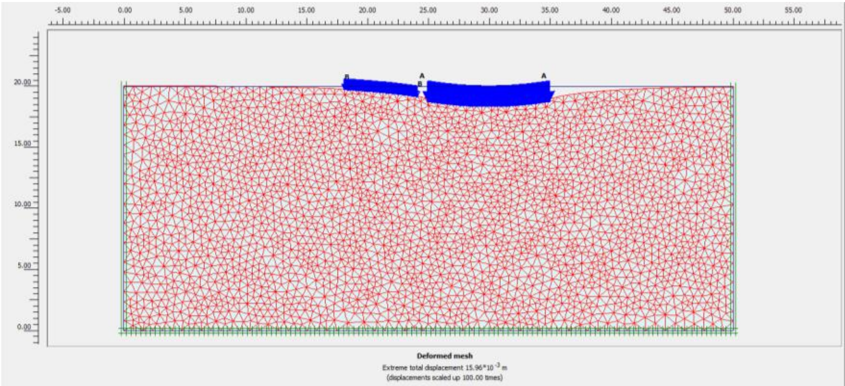

Fig. 7. Example of the deformed mesh after loading (displacements magnified 100 times).

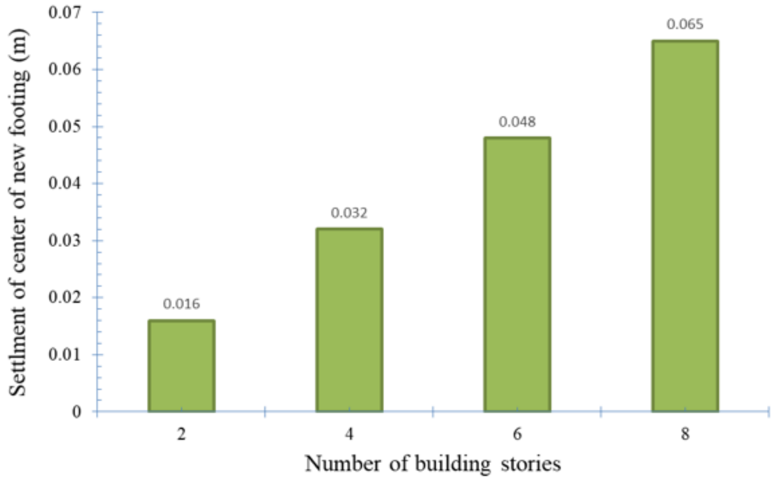

Fig. 8. Final settlement at the center of the new building foundation versus the number of stories.

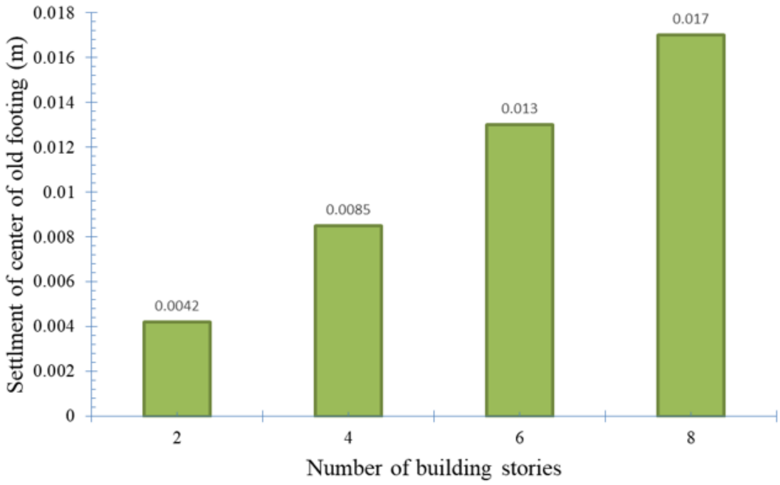

Fig. 9. Final settlement at the center of the existing building foundation versus the number of stories.

The first notable observation from both graphs is that, as expected, settlement increases with the number of stories. According to Fig. 8, the settlement at the center of the new building foundation was calculated as 16 mm for the 2-story case, 32 mm for 4 stories, 48 mm for 6 stories, and 65 mm for 8 stories. In contrast, Fig. 9 shows that the center of the existing building foundation experienced settlements of approximately 4 mm, 8.5 mm, 13 mm, and 17 mm corresponding to the construction of 2-, 4-, 6-, and 8-story new buildings, respectively. A key point from comparing these two graphs is that the settlement of the adjacent existing building is noticeably smaller than that of the new building. However, even a 2-story new building induces nearly 5 mm of settlement in the existing structure. These results indicate that if the new building is 8 stories high and the foundations are spaced 2 m apart, approximately 17 mm of settlement may occur in the pre-existing structure, which could potentially lead to cracking and architectural damage.

4.2. Effect of the new foundation width

Another important factor influencing surface deformations is the loaded area; in other words, the foundation width of the new building is one of the main factors causing settlement in adjacent structures. In this section, to investigate the effect of the new foundation width on the deformation and settlement of the existing building, all other model parameters were kept constant while only the foundation width of the new building was varied. The widths considered, 6, 8, 10, and 12 m, represent the majority of buildings in the study area. Since the objective of this parametric study is to examine the effect of the new foundation width on the settlement of the existing structure, all other influential factors were kept constant across all models. Accordingly, the horizontal distance between the two foundations was fixed at 1 m, the width of the existing foundation was set to 6 m, and the height of the new building was 6 stories for all models.

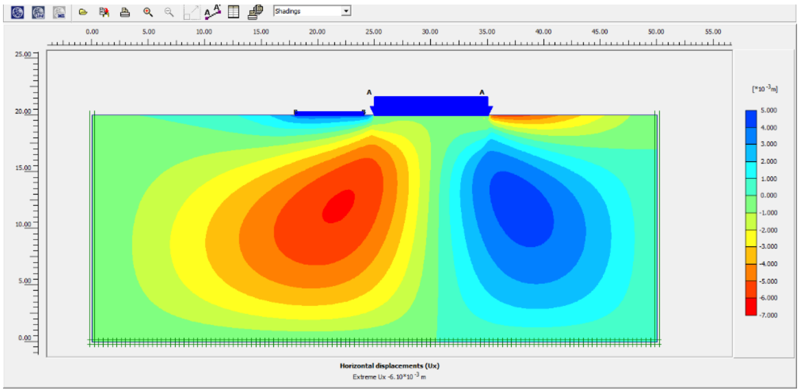

Fig. 10. Example of the horizontal displacement pattern for a 6-story building with a 10 m foundation width and 1 m foundation spacing.

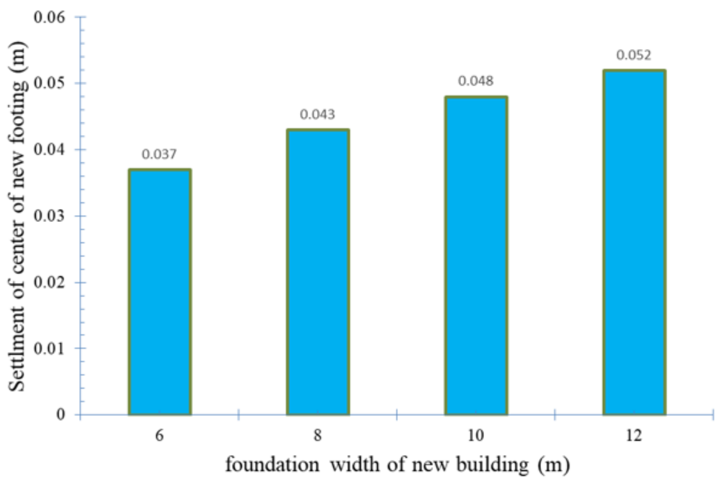

Fig. 11. Final settlement at the center of the new building foundation versus foundation width.

As clearly observed in these figures, increasing the foundation width from 6 m to 12 m leads to higher settlement at the center of the new building. This is due to the increased loading area in the numerical model. Additionally, as is known, a wider foundation exhibits greater flexibility, resulting in larger displacements at its center. According to the literature, increasing the foundation length can also enhance its bending, which contributes to the increased settlement at the foundation center. For the 6-story building, the settlement at the new foundation center was calculated as 37 mm for a 6 m width, 43 mm for 8 m, 48 mm for 10 m, and 52 mm for 12 m. Overall, this indicates that, for a building with a fixed number of stories, increasing the foundation width does not cause a significant change in settlement magnitude.

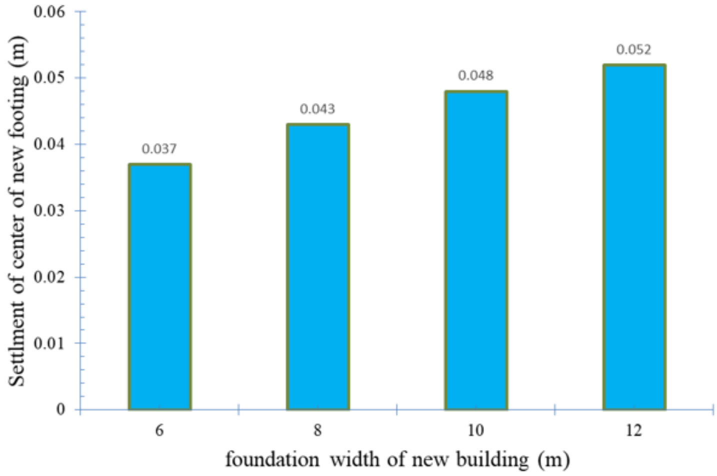

Fig. 12. Final settlement at the center of the existing building foundation versus foundation width.

Based on the data in Fig. 12, if the new foundation width is 6 m, the settlement at the center of the existing building foundation is 10 mm. Increasing the new foundation width to 8 m raises the settlement to 12 mm. Further increases to 10 m and 12 m result in 13 mm settlement, showing that increasing the foundation width beyond 10 m has little effect on the settlement of the existing structure.

4.2. Effect of the distance between structures

Due to the limited availability of suitable land in urban environments and the increasing economic value of existing plots, constructing buildings in close proximity has become inevitable. When adjacent structures are constructed within overlapping stress fields, they can exert various effects on each other. Therefore, the distance between a new building and an existing structure is a critical factor influencing deformations and settlements in the pre-existing building. This section investigates the effect of the distance between the new and existing structures on induced settlements and displacements.

To evaluate the effect of foundation spacing, all other parameters, including the number of stories, foundation widths of both the new and existing structures, and geomechanical properties of the subsoil, were kept constant, while the distance between the foundations was varied. Four spacing scenarios were considered: nearly touching foundations, 1 m spacing, 3 m spacing (equivalent to half of the existing foundation width, *B*/2), and 6 m spacing (equivalent to one full width, B). For this study, the new foundation width was set to 10 m, the existing foundation width to 6 m, and the new building height to 6 stories.

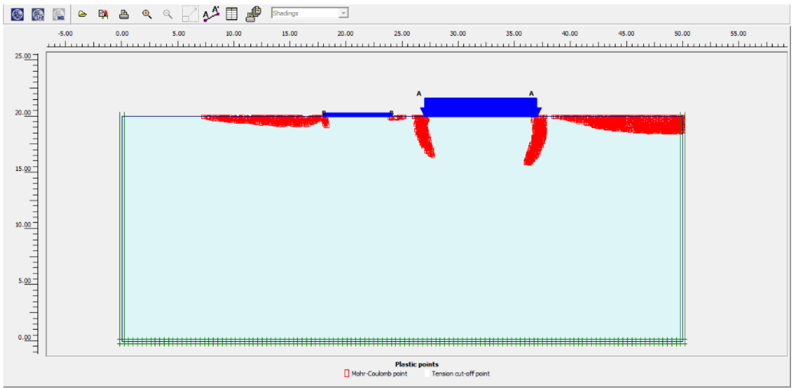

Fig. 13. Example of plastic points formation for a 6-story building with a 10 m foundation width and 3 m spacing; plastic points indicate nodes where the stress has reached a level causing plastic deformations.

As expected, increasing the distance between the new and existing structures reduces the induced settlement at the center of the existing foundation. According to the results shown in Fig. 15, when the foundations are nearly touching, the settlement at the center of the existing building is approximately 16 mm. Increasing the distance to 1 m reduces the settlement to 13 mm. When the spacing is further increased to 3 m (equivalent to half of the existing foundation width, 0.5 B), the induced settlement decreases to about 8 mm. Finally, with a spacing of 6 m (equivalent to the full foundation width, 1 B), the settlement at the center of the existing structure reduces to 4 mm. These results clearly indicate that the distance between adjacent foundations has a significant influence on induced settlements and displacements. The calculations show that increasing the spacing by 0.5 B reduces the induced settlement at the existing building center by approximately 50 %. Increasing the spacing to 1 B further decreases the induced settlement from 16 mm to around 4 mm, corresponding to a 75 % reduction.

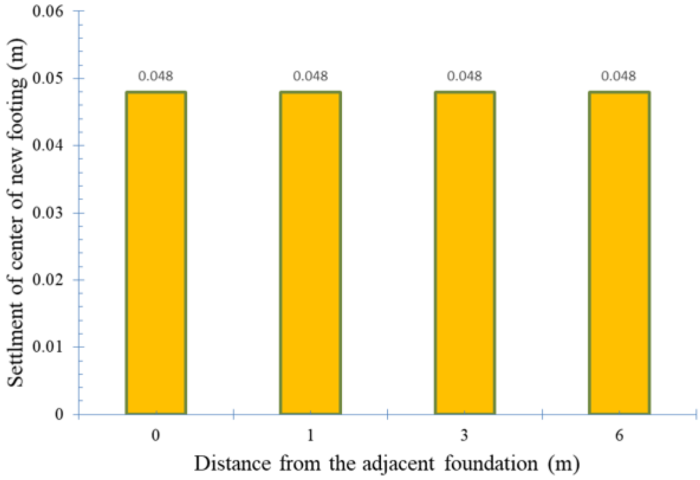

Fig. 14. Final settlement at the center of the new building foundation versus distance from the adjacent foundation.

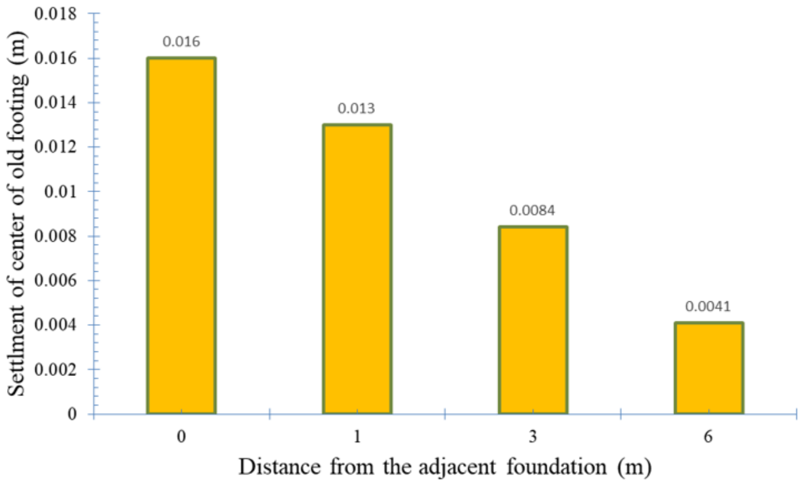

Fig. 15. Final settlement at the center of the existing building foundation versus distance from the adjacent foundation.

5. Conclusion

As is well known, multiple factors influence the settlement of existing structures due to the construction of new buildings. In this study, the main factors examined in a parametric analysis included the number of stories of the new building, the width of its foundation, and the horizontal distance between the new and existing structures. The subsoil in this study was assumed to be sandy.

Buildings and structural elements were modeled in PLAXIS using plate elements. Foundations were represented as structural elements, and the number of stories was simulated as distributed loads. According to applicable codes, a load of 10 kN per story was assigned in the model. The main findings from the numerical analyses are summarized as follows:

1. Number of Stories: One of the most influential factors on the settlement of existing structures is the number of stories of the new building. As expected, increasing the number of stories increased settlement at both the center of the new and existing foundations. While settlements in the new building were significantly higher than in the existing structure, the effect on the pre-existing building was still notable; for example, adding two stories to the new building induced approximately 5 mm of settlement at the center of the existing foundation.

2. Foundation Width: Another influential factor is the foundation width of the new building. The results indicate that, in general, changing the foundation width, while keeping other parameters such as loading, number of stories, and subsoil properties constant, has little effect on settlement of the adjacent structure. Specifically, increasing the new foundation width from 6 m to 12 m resulted in only a 3 mm increase in settlement of the existing building, which is negligible.

3. Distance between Structures: The horizontal distance between adjacent buildings was also investigated. The results showed that increasing the spacing between buildings has a significant effect on reducing induced settlements in the existing structure. For instance, increasing the distance to 3 m (equivalent to half the existing foundation width) reduced the induced settlement by approximately 50 %.

6. Engineering implications

The findings of this study provide several practical insights for urban geotechnical and structural engineering. One of the most influential factors affecting settlement of existing structures is the number of stories of the new building. As expected, increasing the number of stories increases settlement at both the new and existing foundations. For example, adding two stories to the new building induced approximately 5 mm of settlement at the center of the existing foundation, which, while smaller than the settlement in the new building, is still notable for design considerations. The foundation width of the new building has a relatively minor effect on adjacent settlements. Increasing the foundation width from 6 m to 12 m, while keeping other parameters constant, resulted in only a 3 mm increase in settlement of the existing structure, which can generally be considered negligible. The spacing between adjacent buildings was found to have the most significant influence. Increasing the distance to 3 m (about half the foundation width) reduced induced settlement in the existing structure by approximately 50 %, highlighting the importance of maintaining sufficient separation between buildings in densely built areas.

Overall, these results emphasize that careful consideration of building height, spacing, and to a lesser extent foundation width, combined with proper soil–foundation interaction assessment, is essential for minimizing settlement risks. The study provides guidance for design strategies that enhance the safety and resilience of adjacent structures, contributing to more effective urban densification planning and mitigation of settlement-induced damage.

Statements & Declarations

Author contributions

Vali Ghaseminejad: Conceptualization, Investigation, Methodology, Formal analysis, Resources, Writing - Original Draft, Writing - Review & Editing.

Seyed Mojtaba Moosavi: Conceptualization, Methodology, Formal analysis, Project administration, Supervision, Writing - Review & Editing.

Taher Zargar Herijani: Investigation, Visualization, Validation, Formal analysis, Resources, Writing - Original Draft, Writing - Review & Editing.

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Data availability

The data presented in this study will be available on interested request from the corresponding author.

Declarations

The authors declare no conflict of interest.

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